



BSI Standards Publication

Gaseous hydrogen — Cylinders and tubes for stationary storage

National foreword

This British Standard is the UK implementation of EN 17533:2020.

The UK participation in its preparation was entrusted to Technical Committee PVE/3/8, Gas containers - Hydrogen technologies.

BSI, as a member of CEN, is obliged to publish EN 17533:2020 as a British Standard. However, attention is drawn to the fact that during the development of this European Standard, the UK committee voted against its approval.

The UK committee submitted a negative vote for this standard for the following reasons:

- The relationship between the main body of the text and Annex B is unclear. There are elements of the text that suggest Annex B is supplementary to the main text, e.g. clause 8.3.1, and others that suggest Annex B replaces the main body of the text, e.g. clause 9, and provides an alternative means to approve cylinders to this standard, but Annex B does not incorporate all requirements of the main body of the text.
- As written, the standard provides an opportunity for cylinders currently in service to be approved against this standard, however it would be extremely difficult to determine the past life of such cylinders and thus it would be unsuitable to approve them against this standard.
- With regard to Annex B, type 2, 3 and 4 transportable gas cylinders converted for use as stationary cylinders should have a maximum life of 30 years, as detailed within the main body of the text.
- The specific requirements such as cylinder protection listed in the main body of the text shall be applied to cylinders being approved under Annex B.

The UK participation in its preparation was entrusted to Technical Committee PVE/3/8, Gas containers - Hydrogen technologies.

A list of organizations represented on this committee can be obtained on request to its committee manager.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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English Version

Gaseous hydrogen - Cylinders and tubes for stationary storage

Hydrogène gazeux - Bouteilles et tubes pour stockage
stationnaire

Gasförmiger Wasserstoff - Flaschen und Großflaschen
zur ortsfesten Lagerung

This European Standard was approved by CEN on 13 August 2019.

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European foreword

This document (EN 17533:2020) has been prepared by Technical Committee CEN/TC 23 “Transportable gas cylinders”, the secretariat of which is held by BSI.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by December 2020, and conflicting national standards shall be withdrawn at the latest by December 2020.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN shall not be held responsible for identifying any or all such patent rights.

According to the CEN-CENELEC Internal Regulations, the national standards organisations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Republic of North Macedonia, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

Introduction

As the use of gaseous hydrogen evolves from the chemical industry into various emerging applications, such as fuel for fuel cells, internal combustion engines and other speciality hydrogen applications, new requirements are foreseen for seamless and composite pressure vessels, including higher number of pressure cycles.

Requirements covering pressure vessels for stationary storage of compressed gaseous hydrogen are listed in this document and are mainly intended to maintain or improve the level of safety for this application.

1 Scope

This document specifies the requirements for the design, manufacture and testing of standalone or manifolded (for some specific tests such as bonfire) cylinders, tubes and other pressure vessels of steel, stainless steel, aluminium alloys or of non-metallic construction material. These are intended for the stationary storage of gaseous hydrogen of up to a maximum water capacity of 10 000 l and a maximum allowable working pressure not exceeding 110 MPa, of seamless metallic construction (Type 1) or of composite construction (Types 2, 3 and 4), hereafter referred to as pressure vessels.

This document is not applicable to Type 2 and 3 vessels with welded liners.

This document is not applicable to pressure vessels used for solid, liquid hydrogen or hybrid cryogenic-high pressure hydrogen storage applications.

This document is not applicable to external piping which can be designed according to recognized standards.

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.

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

EN ISO 527-2, *Plastics — Determination of tensile properties — Part 2: Test conditions for moulding and extrusion plastics*

EN ISO 1519, *Paints and varnishes — Bend test (cylindrical mandrel)*

EN ISO 2808, *Paints and varnishes — Determination of film thickness*

EN ISO 2812-1, *Paints and varnishes — Determination of resistance to liquids — Part 1: Immersion in liquids other than water*

EN ISO 4624, *Paints and varnishes — Pull-off test for adhesion*

EN ISO 6272-2, *Paints and varnishes — Rapid-deformation (impact resistance) tests — Part 2: Falling-weight test, small-area indenter*

EN ISO 6506-1, *Metallic materials — Brinell hardness test — Part 1: Test method*

EN ISO 7225, *Gas cylinders — Precautionary labels*

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

EN ISO 9227, *Corrosion tests in artificial atmospheres — Salt spray tests*

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

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

EN ISO 9809-3, *Gas cylinders — Refillable seamless steel gas cylinders — Design, construction and testing — Part 3: Normalized steel cylinders*

ISO 9809-4, *Gas cylinders — Refillable seamless steel gas cylinders — Design, construction and testing — Part 4: Stainless steel cylinders with an R_m value of less than 1 100 MPa*

EN ISO 11114-1, *Gas cylinders — Compatibility of cylinder and valve materials with gas contents — Part 1: Metallic materials*

EN ISO 11114-2, *Gas cylinders — Compatibility of cylinder and valve materials with gas contents — Part 2: Non-metallic materials*

EN ISO 11114-4, *Transportable gas cylinders — Compatibility of cylinder and valve materials with gas contents — Part 4: Test methods for selecting steels resistant to hydrogen embrittlement*

ISO 11119-1, *Gas cylinders — Refillable composite gas cylinders and tubes — Design, construction and testing — Part 1: Hoop wrapped fibre reinforced composite gas cylinders and tubes up to 450 l*

ISO 11119-2, *Gas cylinders — Refillable composite gas cylinders and tubes — Design, construction and testing — Part 2: Fully wrapped fibre reinforced composite gas cylinders and tubes up to 450 l with load-sharing metal liners*

ISO 11119-3, *Gas cylinders — Refillable composite gas cylinders and tubes — Design, construction and testing — Part 3: Fully wrapped fibre reinforced composite gas cylinders and tubes up to 450L with non-load-sharing metallic or non-metallic liners*

EN ISO 11120, *Gas cylinders — Refillable seamless steel tubes of water capacity between 150 l and 3000 l — Design, construction and testing*

EN ISO 11357-2, *Plastics — Differential scanning calorimetry (DSC) — Part 2: Determination of glass transition temperature*

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

ISO 12108, *Metallic materials — Fatigue testing — Fatigue crack growth method*

EN ISO 14130, *Fibre-reinforced plastic composites — Determination of apparent interlaminar shear strength by short-beam method*

EN ISO 16474-1, *Paints and varnishes — Methods of exposure to laboratory light sources — Part 1: General guidance*

EN ISO 16474-3, *Paints and varnishes — Methods of exposure to laboratory light sources — Part 3: Fluorescent UV lamps*

EN 13322-2, *Transportable gas cylinders — Refillable welded steel gas cylinders — Design and construction — Part 2: Stainless steel*

ASTM D3170/D3170M - 14, *Standard Test Method for Chipping Resistance of Coatings*

ASTM E647, *Standard Test Method for Measurement of Fatigue Crack Growth Rates*

3 Terms, definitions and symbols

3.1 Terms and definitions

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

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

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

3.1.1

autofrettage

pressure application procedure which strains the metal *liner* (3.1.13) past its yield point sufficiently to cause permanent plastic deformation, resulting in the liner having compressive stresses and the fibres having tensile stresses when at zero internal gauge pressure

3.1.2

autofrettage pressure

pressure within the overwrapped composite pressure vessel at which the required distribution of stresses between the *liner* (3.1.13) and the *composite overwrap* (3.1.6) is established

3.1.3

batch of pressure vessels

batch of pressure liners

set of manufactured *finished pressure vessels* (3.1.10) or *liners* (3.1.13) subject to a manufacturing quality pass/fail criterion based on the results of specified tests performed on a specified number of units from that set

3.1.4

boss

dome shaped metallic component mounted on one end or on the two ends of a non-metallic *liner* (3.1.13) with a neck providing an opening and/or an external element of mechanical support

3.1.5

burst pressure

highest pressure reached in a cylinder during a burst test

3.1.6

composite overwrap

combination of fibres (including steel wire) and *matrix* (3.1.15)

3.1.7

controlled tension winding

process used in manufacturing composite pressure vessels with metal *liners* (3.1.13) by which compressive stresses in the liner and tensile stresses in the *composite overwrap* (3.1.6) at zero internal pressure are obtained by winding the reinforcing fibres under controlled tension

3.1.8

cycle amplitude

ratio of pressure increase to maximum pressure in a *pressure cycle* (3.1.21)

Note 1 to entry: Cycle amplitude is expressed in %.

3.1.9

design change

change in the selection of structural materials or dimensional change exceeding the tolerances as on the design drawings

3.1.10

finished pressure vessel

pressure vessel, which is ready for use, typical of normal production, complete with identification marks and external coating including integral insulation specified by the manufacturer, but free from non-integral insulation or protection

Note 1 to entry: In the framework of this document, a tube or a cylinder is a finished pressure vessel.

3.1.11

full cycle

cycle of pressure amplitude between the *maximum allowable working pressure (MAWP)* (3.1.17) and 10 % of the MAWP

3.1.12

leakage

release of hydrogen through a crack, pore, or similar defect

Note 1 to entry: Permeation through the wall of a Type 4 pressure vessel that is less than the rates described in A.13 is not considered a leakage.

3.1.13

liner

inner portion of the composite cylinder, comprising a metallic or non-metallic vessel, whose purpose is both to contain the gas and transmit the gas pressure to the fibres

3.1.14

load-sharing liner

liner (3.1.13) that has a *burst pressure* (3.1.5) of at least 5 % of the minimum burst pressure of the finished composite cylinder

3.1.15

matrix

material that is used to bind and hold the fibres in place

3.1.16

maximum allowable temperature

maximum temperature of any part of the pressure vessel for which it is designed (or intended to be used if Annex B is followed)

3.1.17**maximum allowable working pressure****MAWP****design pressure**

maximum pressure to which the component is designed to be subjected to and which is the basis for determining the strength of the component under consideration

3.1.18**minimum allowable temperature**

minimum temperature of any part of the pressure vessel for which it is designed (or intended to be used if Annex B is followed)

3.1.19**operator**

entity legally responsible for the use and maintenance of the vessel

3.1.20**pressure-activated pressure relief device****pressure-activated PRD**

device designed to release pressure in order to prevent a rise in pressure above a specified value due to emergency or abnormal conditions

Note 1 to entry: Pressure-activated PRDs may be either re-closing devices (such as valves) or non-re-closing devices (such as rupture disks).

3.1.21**pressure cycle**

pressure variation composed of one period of monotonic pressure increase up to a peak pressure followed by one period of monotonic pressure decrease

Note 1 to entry: Pressure variations exclusively due to variations of ambient temperature are not counted as pressure cycles.

3.1.22**pressure cycle life**

maximum number of *pressure cycles* (3.1.21) in hydrogen service that the pressure vessel is designed to withstand in service

3.1.23**pre-stress**

process of applying *autofrettage* (3.1.1) or *controlled tension winding* (3.1.7)

3.1.24**service life**

maximum period for which the pressure vessel is designed to be in service based on fatigue life and stress rupture characteristics of composite cylinders

Note 1 to entry: Service life is expressed in years.

Note 2 to entry: Service life usually depends on the *pressure cycle* (3.1.21) or other service conditions and requirements from applicable standards. For composite cylinders, life in years is a requirement to address reliability under stress rupture conditions, which is also an underlying basis for the required *stress ratios* (3.1.29).

3.1.25

shallow pressure cycle

pressure cycle (3.1.21) from the *MAWP* (3.1.17) to not less than 70 % of the *MAWP*

3.1.26

shallow pressure cycle life

maximum number of *shallow pressure cycles* (3.1.25) that the pressure vessel is designed to withstand in hydrogen service

3.1.27

stationary storage

pressurized storage in a fixed location for a fixed purpose that is not transported while pressurized

3.1.28

stationary test pressure

TP

required pressure applied during a pressure test for the pressure vessel used in stationary service

Note 1 to entry: If Annex B is used, this is not to be confused with the *test pressure* (3.1.30) P_h used in e.g. the EN ISO 9809 series for design purposes as transportable gas cylinder.

3.1.29

stress ratio

stress in fibre at specified minimum *burst pressure* (3.1.5) divided by stress at the *MAWP* (3.1.17)

3.1.30

test pressure

required pressure applied during a pressure test

3.1.31

thermally activated pressure relief device

thermally activated PRD

device that activates by temperature to release pressure and prevent a pressure vessel from bursting due to fire effects and which will activate regardless of the vessel pressure

3.1.32

thermoplastic material

plastic capable of being repeatedly softened by an increase of temperature and hardened by a decrease of temperature

3.1.33

Type 1 pressure vessel

metal seamless cylindrical pressure vessel

Note 1 to entry: All metal multi-layered non-seamless vessels are not covered in this document. For reference, several types of multi-layered pressure vessels are addressed by ASME BPVC Section VII and Chinese standards GB 150 and GB/T 26466.

3.1.34

Type 2 pressure vessel

hoop wrapped cylindrical pressure vessel with a load-sharing metal *liner* (3.1.13) and composite reinforcement on the cylindrical part only

3.1.35**Type 3 pressure vessel**

fully wrapped cylindrical pressure vessel with a load-sharing metal *liner* (3.1.13) and composite reinforcement on both the cylindrical part and dome ends

3.1.36**Type 4 pressure vessel**

fully wrapped cylindrical pressure vessel with a *non-load-sharing liner* (3.1.37) and composite reinforcement on both the cylindrical part and the dome ends

3.1.37**non-load-sharing liner**

liner (3.1.13) that has a *burst pressure* (3.1.5) less than 5 % of the nominal burst pressure of the finished composite cylinder

3.1.38**working pressure**

settled pressure of a fully filled cylinder at a uniform temperature of 15 °C

Note 1 to entry: This term is normally used for transportable cylinders, see Annex B.

[SOURCE: ISO 11439:2013, 3.23, modified — Note 1 to entry has been added.]

3.2 Symbols

ΔP_i	variation of pressure during a given actual pressure cycle (in bar)
$\Delta P_{\max}$	variation of pressure during the pressure test specified in the reference standard (in bar)
F	design stress factor (ratio of equivalent wall stress at test pressure P_h to guarantee minimum yield strength)
F_a	hydrogen accelerating factor (see B.2.2.6), this factor is the multiplication factor to be applied on equivalent cycles n_{eq} calculation to take into account the ageing effect of H ₂ on cycling.
n_{eq}	number of cycles equivalent to full cycles (guaranteed in a given standard)
n_i	number of pressure cycle corresponding to ΔP_i
P_h	test pressure (in bar)
P_w	working pressure (in bar)
a	flaw size
N	number of pressure cycles
da/dN	crack growth rate, da/dN_{low} and da/dN_{high} are given in Table 5
C	constant, see Table 5
m	constant, see Table 5
C_H	constant when fatigue is performed in hydrogen
ΔK	range of the stress intensity factor during the fatigue cycle
ΔK_c	range of the stress intensity factor at which transition in the da/dN from low to high occurs

R_k	stress intensity factor
$K_{\min}$	minimum stress intensity factor during the fatigue cycle
$K_{\max}$	maximum stress intensity factor during the fatigue cycle
$K_{\max}$	given value, see 8.3.5.6

4 Specified service conditions

4.1 Maximum allowable working pressure

The maximum allowable working pressure shall be specified by the pressure vessel manufacturer, shall not be less than 15 MPa and shall not exceed 110 MPa.

4.2 Maximum allowable energy content

The maximum allowable energy content of a single pressure vessel shall not exceed 300 000 MPa·l.

4.3 Maximum and minimum allowable temperature

The maximum allowable temperature and the minimum allowable temperature shall be specified by the pressure vessel manufacturer and noted on the name plate.

The specified value for the maximum allowable temperature shall not be less than 50 °C and shall not exceed 85 °C.

The specified value for the minimum allowable temperature shall not exceed –25 °C and shall not be less than –50 °C.

The manufacturer may specify a distinct maximum temperature not to be exceeded during maintenance (e.g. for painting).

4.4 Pressure cycle life

The pressure cycle life in hydrogen service shall be specified by the pressure vessel manufacturer.

The owner/operator may elect to further restrict to number of cycles allowed.

4.5 Shallow pressure cycle life

A shallow pressure cycle life may optionally be specified by the pressure vessel manufacturer or user. In this case, the shallow pressure cycle life shall be at least three times the pressure cycle life.

The shallow cycle life shall be calculated according to one of the methods given in 4.6.3, 8.3.5 or experimentally determined according to methods described in A.7.

4.6 Effective pressure cycle count and maximum number of pressure cycles allowed in service

4.6.1 General

One of the following methods shall be used to determine the pressure cycles life of the cylinder.

4.6.2 Pressure cycles calculation method — Method described in Annex B

For all types of vessels, the number of cycles equivalent to full cycles (guaranteed in a given standard) can be calculated according to the formula given in Annex B.

4.6.3 Pressure cycles calculation method — Goodman diagrams method described in Annex F

The cycle life may be determined by the use of a Goodman diagram and Miner's Rule. The Goodman diagram shall be based on fatigue testing of similar materials and construction as the vessel to be qualified. An example of this approach is provided in Annex F.

4.7 Service life

The service life shall be specified by the pressure vessel manufacturer.

For Type 2, Type 3, and Type 4 designs incorporating aramid or glass fibre, the specified service life shall not exceed 30 years.

The duration of service is also limited by the specified pressure cycle life. The operator is responsible for monitoring the cycles placed on the pressure vessels and removing them from service when their rated life has been reached. For example, a pressure vessel specified for 150 000 cycles and subjected to a pressure cycle every hour will need to be removed from service after 17 years.

5 Additional service conditions

5.1 Environmental conditions

The manufacturer shall specify the environmental conditions for which the pressure vessel has been designed as well as any protection to be provided at point of use, such as external protection from extreme solar radiation.

Precautions shall be taken against drop or impact (particularly during installation). If drop or impact does occur, an inspection shall be conducted.

This information shall be included in the statement of service provided by the manufacturer as required by 6.2.

Immersion in fluids, additional coating, protecting layer or medium isolating the cylinders or generating retention of fluids of any kind requires written approval from the manufacturer.

5.2 Fire conditions

The owner/operator shall assess the outcome of a risk analysis to demonstrate that in case of a fire, overall safety will be maintained.

For protection, several solutions can be used (e.g. extinguishing devices, fire retardants, PRD, intumescent paints, etc.).

When regulations or risk analysis require the installation of a pressure relief device, see for information suggested design and test procedures in Annex G.

6 Information to be recorded

6.1 General

The pressure vessel manufacturer shall keep on file the information specified herein. This information shall be retained for the intended life of the pressure vessel.

6.2 Statement of service

A statement of service shall be provided by the manufacturer of the pressure vessel to the user. This statement of service shall include the following:

- a) the name and address of the pressure vessel manufacturer;
- b) the service conditions as specified in Clause 4 and Clause 5, including a warning about the need for measures to prevent specified limitations, such as temperature limits and cycle life, from being exceeded;
- c) a statement that the pressure vessel design is suitable for use in the service conditions provided in Clauses 4 and 5;
- d) a description of the pressure vessel design, including diameter (mm), length (mm), internal volume (l), empty weight (kg), and port geometry;
- e) if applicable, a specification of the pressure relief performance required to prevent violent rupture in case of exposure to fire conditions, as specified in 5.2;
- f) a specification for the support methods, external protection, protective coatings and any other items required, but not provided with the pressure vessel;
- g) a statement that the number of cycles of operations shall be determined and that the actual number of cycles shall be monitored;
- h) any other information and instructions necessary to ensure the safe use and inspection of the pressure vessel, including those specified hereafter, where relevant:
 - for Type 2, Type 3, and Type 4 designs requiring protection against exposure to UV emissions, instructions shall require that this protection be provided by the installation;
 - for Type 4 designs, the manufacturer shall:
 - specify the minimum residual pressure (MRP) in normal operation. The specified MRP shall not exceed 15 % of the MAWP;
 - specify the maximum depressurization rate during normal operation, which shall be lower than 20 MPa/min;
 - provide a procedure for complete depressurization from MRP without liner collapse.

NOTE Annex E provides further typical information on the manufacturer's instructions for handling, use and inspection of pressure vessels.

6.3 Design drawings and information

All pressure vessel drawings and related technical data shall be kept on file by the pressure vessel manufacturer and shall show the following information:

- a) title, reference number, date of issue, and revision numbers with dates of issue, if applicable;
- b) the MAWP;
- c) the operating process temperature range;
- d) the specified service conditions, in addition to the MAWP, as specified in Clauses 4 and 5;
- e) dimensions complete with tolerances, including details of end closure shapes with minimum thickness and openings;
- f) mass, complete with tolerance;
- g) material specifications, complete with minimum mechanical and chemical properties and tolerance ranges and, for metal pressure vessels, metal liners and bosses, the specified hardness range and maximum allowable defect size;
- h) autofrettage pressure range and duration;
- i) test pressure as carried out by the manufacturer;

NOTE Applicable regulation can require a different value.

- j) details on exterior protective coating.

6.4 Stress analysis report

The manufacturer shall produce a stress analysis report as required by 8.1.1, including a table summarizing the determined stresses. The manufacturer shall keep this report on file.

6.5 Material property data

The manufacturer shall keep the following information on file, as applicable, and make it available to regulatory authorities or inspectors on request:

- a) detailed description of the materials and tolerances of the material properties used in the design, including test data characterizing the mechanical properties and the suitability of the materials for service under the conditions specified in Clauses 4 and 5;
- b) published specifications for composite materials, as well as the material manufacturer's recommendations for storage conditions and shelf life;
- c) the fibre manufacturer's certification that each shipment conforms to the manufacturer's specifications for the product.

6.6 Manufacturing data

Details of all fabrication processes, tolerances, non-destructive examinations, batch tests and production tests shall be specified and kept on file by the manufacturer.

The manufacturer shall specify the minimum burst pressure for the design. In no case shall the minimum specified burst pressure be less than the minimum burst pressure specified in this document in relation to the MAWP.

Surface finish, thread details, acceptance criteria for non-destructive examination, and lot sizes for batch tests shall also be specified by the manufacturer and kept on file. Examples of procedures to determine the acceptable defect sizes are given in Annex D.

The manufacturing data specified in 8.2.5, 8.2.6 and 8.2.7, along with the results of non-destructive examinations, batch tests, and production tests shall be kept on file by the manufacturer.

6.7 Retention of records

The design and manufacturing data kept on file, as specified in 6.5, 6.6 and 8.4.1, shall be retained by the manufacturer for a duration of at least the service life of the pressure vessel plus five years from the date of manufacture.

7 Material properties

7.1 Compatibility

The design shall not have incompatible materials in contact with each other. All materials in contact with hydrogen shall be suitable for use in hydrogen, according to the criteria of EN ISO 11114-1, EN ISO 11114-2 and EN ISO 11114-4 as applicable.

NOTE Guidance on hydrogen compatibility can be found in References [10], [12], [14], [21] and [25].

7.2 Steel

Steels for pressure vessels, seamless liners, and bosses shall either conform to the materials requirements of EN ISO 9809-1 for pressure vessels of water capacities up to 450 l and of EN ISO 11120 for pressure vessels of water capacities greater than 450 l and to EN ISO 11114-1, or be suitable with hydrogen according to EN ISO 11114-4.

7.3 Stainless steels

Stainless steels for pressure vessels, liners, and bosses shall either conform to the specific materials requirements of ISO 9809-4 for hydrogen service and to EN ISO 11114-1, or be suitable with hydrogen according to EN ISO 11114-4.

7.4 Aluminium alloys

Aluminium alloys for pressure vessels, liners, and bosses shall conform to the materials requirements of EN ISO 7866.

Aluminium alloys not covered by the materials requirements of EN ISO 7866 may be used for bosses only, provided that they are suitable for use in hydrogen according to the criteria of EN ISO 11114-1 and 11114-4.

7.5 Fibre material

Structural reinforcing fibre material types shall be carbon fibre, aramid fibre or glass fibre, or any mixture thereof.

7.6 Resins

The material for impregnation may be thermosetting or thermoplastic resins. Examples of suitable matrix materials are epoxy, modified epoxy, polyester and vinyl-ester thermosetting plastics, as well as polyethylene and polyamide thermoplastic.

The glass transition temperature of the resin material shall be determined in accordance with EN ISO 11357-2. The glass transition temperature shall be at least 15 °C above the maximum allowable temperature.

7.7 Plastic liner material

The polymeric material used for plastic liners shall be compatible with the service conditions specified in Clauses 4 and 5.

Plastic liner materials shall be compatible with requirements listed in EN ISO 11114-2.

For the thermoplastic materials, the Vicat softening temperature per EN ISO 306 shall be at least 90 °C, and its melting temperature at least 100 °C.

8 Requirements for new designs

8.1 General considerations

8.1.1 Stress analysis

For all design types, a stress analysis should be performed using finite element analysis or a similar validated numerical method that includes geometric and material nonlinearities as required to establish the minimum design wall thickness and confirm the required stress ratios specified in 8.1.2.1 are met. It shall include the determination of the stresses in the liners and fibres of composite designs.

Alternatively, for Type 1, methods described in the EN ISO 9809 series or EN ISO 11120 can be used. For Type 2 and Type 3 designs, the stresses in the composite and in the liner after pre-stress shall be calculated at the zero-gauge pressure, MAWP, test pressure and design burst pressure. The calculations shall take account of nonlinear material behaviour of the liner to establish the stress distributions. Calculations shall be transformed into the direction of the fibre for hoop and helically wound layers.

For Type 2 and Type 3, the limits within which the autofrettage pressure shall fall shall be calculated and specified.

For Type 4 designs, the stresses in the composite shall be calculated in the tangential and longitudinal direction of the pressure vessel. The pressures used for these calculations shall be the zero-gauge pressure, MAWP, test pressure and design burst pressure. The calculations shall establish the stress distribution throughout the pressure vessel. Calculations shall be transformed into the direction of the fibre for hoop and helically wound layers.

Stress calculations shall include:

- a) an analysis method with capability for nonlinear materials, such as a special purpose computer program or a finite element analysis program;
- b) suitable modelling of the elastic-plastic stress-strain curve for the liner material;
- c) suitable modelling of the mechanical properties of the composite materials;

- d) calculations at the autofrettage pressure, zero-gauge pressure after autofrettage, MAWP, and minimum burst pressure;
- e) pre-stresses from the winding tension; and
- f) in the case of a hybrid composite overwrap, load share between the different fibres based on the different elastic moduli of the fibres.

8.1.2 Burst pressure and fibre stress ratio

8.1.2.1 Pressure vessel

The minimum actual burst pressure of the pressure vessel shall not be less than the values given in Table 1. This pressure shall be verified on one unit per manufacturing lot. Test shall be done according to procedure described in A.6.

For Type 2, Type 3 and Type 4 designs, the stress ratio in the composite overwrap shall also meet the minimum stress ratio requirements of Table 1. Methods for verifying stress ratios are provided in Annex C.

In a hybrid construction, the applicable stress ratio requirements shall be met in one of the two 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.

Table 1 — Minimum stress ratios and burst pressures

Construction	Minimum stress ratio ^a			Minimum actual burst pressure ^b			
	Type 2	Type 3	Type 4	Type 1	Type 2	Type 3	Type 4
All-Metal	—	—	—	2	—	—	—
Glass	2,65	3,5	3,5	—	2,4	3,4	3,5
Aramid	2,25	3,0	3,0	—	2,25	2,9	3,0
Carbon	2,25	2,25	2,25	—	2,25	2,25	2,25
^a Fibre stress at the minimum burst pressure divided by the fibre stress at the MAWP.							
^b Burst pressures are expressed as a factor of the MAWP.							

Annex H gives information regarding the development and selection of a factor of safety for carbon fibre reinforced pressure tubes.

8.1.2.2 Type 2 vessel liner burst pressure

For Type 2 designs, the un-reinforced metal liner shall have a minimum burst pressure of 1,125 times the MAWP, see also Annex B.

8.1.3 Test pressure

For all design types, the manufacturer shall specify the test pressure. The test pressure specified shall be at least 1,25 times the MAWP pressure, see also Annex B.

The test procedure should be done according to A.17.

NOTE Some regulations require higher test pressures.

8.1.4 Maximum defect size in metallic materials

The manufacturer shall specify the maximum allowable defect size in pressure bearing metallic materials (pressure vessel, liner or boss). The method to detect the maximum allowable defect depth shall be specified (e.g. the EN ISO 9809 series) and not be greater than 5 % of the wall thickness.

At all times, the wall thickness shall not be less than the minimum design thickness.

Defects larger than the specified maximum size shall be detectable by non-destructive examination.

8.1.5 Protection of liner and boss against corrosion

As a general requirement, the vessel design is to protect the components from corrosion from the environment it is to be sited in.

In particular, if carbon fibre reinforcement is used, the design shall incorporate means to prevent galvanic corrosion of metallic components of the pressure vessel (e.g. appropriate insulating coating, inner glass fibre, etc.).

An inner glass fibre wound and resin layer may be used for metallic liners. A glass cloth or resin layer may be used between a metallic end nozzle and the laminate.

Steel liners shall be protected against corrosion prior to wrapping for all types of fibres.

8.1.6 Resistance to UV emissions

Materials on the outside of the pressure vessel, including paint or polymeric coating, if applied, or the composite if no coating is applied, shall be resistant to UV emissions. The materials shall be subjected to 1 000 h of exposure to UVA radiation per EN ISO 16474-1 and EN ISO 16474-3. The gloss loss shall be less than 20 %.

8.1.7 Resistance to humidity

Fibre/resin reinforcement shall be resistant to humidity, as measured by short beam shear testing, so that it maintains integrity over its lifetime. Resin system materials shall be tested on a sample test panel representative of the composite overwrap, in accordance with EN ISO 14130. Following a 24-h water boil, the composite shall have a minimum shear strength of 13,8 MPa.

8.1.8 Protective layer

An optional external layer of laminate may be provided for the protection of the structural laminate layer from damage due to impact, ultraviolet radiation or other environmental exposure, fire or abrasive conditions.

This layer shall not be considered in the calculation on the stress levels in the vessel and shall not be applied to the vessel used for the qualification testing.

8.2 Construction and workmanship

8.2.1 Materials

Type 1 designs and Type 2 liners shall be of seamless construction using carbon steel, stainless steel or aluminium alloys that comply with the materials requirements in 7.2, 7.3, or 7.4, as appropriate.

Type 3 liners shall be constructed from aluminium alloys, carbon steel or stainless steels, and shall be seamless. They shall comply with the materials requirements in 7.2, 7.3 or 7.4, as appropriate.

For Type 3 liners subjected to cold-forming or cryo-forming processes, heat treatment of the pre-form component is not required. Liners that have been cold-formed or cryo-formed shall not be subjected to any subsequent heat treatment or to additional heat application, such as welding, or possibly elevated temperature curing of the composite, which degrades the liner properties.

Type 4 liners shall meet the requirements of the materials requirements in 7.7 and may be of seamless or welded construction.

8.2.2 Openings, neck threads, neck ring, foot ring, attachment for support

Pressure vessels may be designed with one or two openings along the central cylinder axis only.

Openings with tapered or parallel threads may be used. Threads shall be clean cut, even, without surface discontinuities, to gauge and conform to International Standards.

When a neck ring, foot ring or attachments for support are provided, it shall be of a material compatible with that of the pressure vessel and shall be securely attached by a method other than welding, brazing or soldering.

8.2.3 Forming

The base ends of Type 1 steel pressure vessels and Type 2 steel liners shall be hot formed using either forging, spinning methods, or deep drawing plate techniques.

The base ends of steel pressure vessels that have been closed by hot spinning shall be inspected using non-destructive examination or methods in EN ISO 9809-1 or other equivalent techniques, and shall be checked to confirm there is no leakage.

A hot spinning process, such as fusion welding, shall not be used to fully close and seal the ends for aluminium pressure vessels and liners.

Metals shall not be added in the process of closure of the ends. Manufacturing defects shall not be corrected by addition of material.

Bases of cylinders closed by hot spinning or other closing method shall be leak tested.

The manufacturer shall employ such manufacturing techniques and apply such tests that will demonstrate to the satisfaction of the inspector that the cylinders do not leak. For guidance, see EN ISO 9809-1 or EN ISO 11120 for steel liners, ISO 9809-4 for stainless steel and EN ISO 7866 for aluminium alloy liners.

Each pressure vessel shall be examined for wall thickness and visual surface defects prior to final assembly. For guidance, see EN ISO 9809-1 or EN ISO 11120 for steel liners, ISO 9809-4 for stainless steel and EN ISO 7866 for aluminium alloy liners.

After end forming, the pressure vessels shall be heat treated to the hardness range specified for the design. Localized heat treatment shall not be used. For guidance, see EN ISO 9809-1 or EN ISO 11120 for steel liners, ISO 9809-4 for stainless steel and EN ISO 7866 for aluminium alloy liners.