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**Gas cylinders — Design, construction  
and testing of refillable composite gas  
cylinders and tubes —**

**Part 2:  
Fully wrapped fibre reinforced  
composite gas cylinders and tubes up  
to 450 l with load-sharing metal liners**

*Bouteilles à gaz — Conception, construction et essais des tubes et  
bouteilles à gaz rechargeables en matériau composite —*

*Partie 2. Tubes et bouteilles à gaz entièrement bobinés en matériau  
composite renforcés de fibres et d'une contenance allant jusqu'à 450 l  
avec liners métalliques structuraux*

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## Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see [www.iso.org/directives](http://www.iso.org/directives)).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see [www.iso.org/patents](http://www.iso.org/patents)).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see [www.iso.org/iso/foreword.html](http://www.iso.org/iso/foreword.html).

This document was prepared by Technical Committee ISO/TC 58, *Gas cylinders*, Subcommittee SC 3, *Cylinder design*.

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](http://www.iso.org/members.html).

This third edition cancels and replaces the second edition (ISO 11119-2:2012), which has been technically revised. It also incorporates the Amendment ISO 11119-2:2012/Amd.1:2014.

The main changes compared to the previous edition are as follows:

- References updated.
- [7.1.3](#) Minimum fibre stress ratios added.
- [8.5.8](#) Drop Test. Addition of new alternative test for cylinders up to and including 50 l water capacity with dedicated compressed gas service. Addition of alternative impact test for tubes 150 l and above.
- [8.5.10](#) Fire resistance test. Changes to the procedure to make the test more consistent. Adding a criteria for tubes above 150 l to be tested for 5 min.
- [8.5.12](#) Torque Test is now only required for taper threads.

A list of all parts in the ISO 11119 series can be found on the ISO website.

## Introduction

The purpose of this document is to provide a specification for the design, manufacture, inspection and testing of cylinders for worldwide usage. The objective is to balance design and economic efficiency against international acceptance and universal utility.

This document aims to eliminate the concern about climate, duplicate inspection and restrictions currently existing because of lack of definitive International Standards and is not to be construed as reflecting on the suitability of the practice of any nation or region.

This document has been written so that it is suitable to be referenced in the UN Model Regulations<sup>[1]</sup>.

This document addresses the general requirements on design, construction and initial inspection and testing of pressure receptacles of the *Recommendations on the transport of dangerous goods: Model regulations* developed by the United Nations<sup>[15]</sup>.

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# Gas cylinders — Design, construction and testing of refillable composite gas cylinders and tubes —

## Part 2:

## Fully wrapped fibre reinforced composite gas cylinders and tubes up to 450 l with load-sharing metal liners

### 1 Scope

This document specifies minimum requirements for the material, design, construction and workmanship, manufacturing processes, examination and testing at time of manufacture for:

- type 3 fully wrapped cylinders or tubes with a load-sharing metal liner and composite reinforcement on both the cylindrical portion and the dome ends;
- water capacities up to 450 l;
- storage and conveyance of compressed or liquefied gases;
- cylinders and tubes with composite reinforcement of carbon fibre, aramid fibre or glass fibre (or a mixture thereof) within a matrix;
- a minimum design life of 15 years.

This document does not address the design, fitting, and performance of removable protective sleeves.

This document does not apply to cylinders with welded liners.

NOTE 1 References to cylinders in this document include composite tubes if appropriate.

NOTE 2 ISO 11439 applies to cylinders intended for use as fuel containers on natural gas vehicles and ISO 11623 covers periodic inspection and re-testing of composite cylinders.

### 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 3341, *Textile glass — Yarns — Determination of breaking force and breaking elongation*

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

ISO 6508-1, *Metallic materials — Rockwell hardness test — Part 1: Test method*

ISO 7225, *Gas cylinders — Precautionary labels*

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

ISO 9809-1, *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, *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 9809-3, *Gas cylinders — Design, construction and testing of refillable seamless steel gas cylinders and tubes — Part 3: Normalized steel cylinders and tubes*

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

ISO 10286, *Gas cylinders — Terminology*

ISO 10618, *Carbon fibre — Determination of tensile properties of resin-impregnated yarn*

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

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 13341, *Gas cylinders — Fitting of valves to gas cylinders*

ISO 13769, *Gas cylinders — Stamp marking*

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

ASTM D7269, *Standard test methods for tensile testing of aramid yarns*

ASTM E1356-08, *Standard Test Method for Assignment of the Glass Transition Temperatures by Differential Scanning Calorimetry*

### 3 Terms and definitions

For the purposes of this document, the terms and definitions in ISO 10286 and the following 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

##### **aramid fibre**

continuous filaments of aramid laid up in tow form

#### 3.2

##### **autofrettage**

pressure application procedure which strains the metal liner past its yield point sufficient to cause permanent plastic deformation, and results in the liner having compressive stresses and the fibres having tensile stresses when at zero internal gauge pressure

#### 3.3

##### **batch**

set of homogeneous items or material

Note 1 to entry: The number of items in a batch can vary according to the context in which the term is used.

**3.4****batch of liners**

production quantity of up to 200 finished liners successively produced (plus units required for destructive testing) of the same nominal diameter, length, thickness and design, from the same material cast and heat treated to the same conditions of temperature and time

**3.5****batch of finished cylinders**

production quantity of up to 200 finished cylinders successively produced by the same manufacturing process plus finished cylinders required for destructive testing, of the same nominal diameter, length, thickness and design

**3.6****burst pressure**

highest pressure reached in a cylinder during a burst test

**3.7****carbon fibre**

continuous filaments of carbon laid up in tow form

**3.8****composite overwrap**

combination of fibres and matrix

**3.9****dedicated gas service**

service in which a cylinder is to be used only with a specified gas or gases

**3.10****equivalent fibre**

fibre from the same material family and similar properties to a fibre used in a previously prototype tested cylinder

**3.11****equivalent liner**

liner of the same alloy family, and that has certified properties and performance so as to be a directly comparable to a liner used in an already approved cylinder

**3.12****equivalent matrix**

resin matrix from the same chemical family and similar properties to the resin matrix used in a previously prototype tested cylinder

**3.14****glass fibre**

continuous filaments of glass laid up in tow form

**3.15****liner**

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

**3.16****matrix**

material used to bind and hold the fibres in place

**3.17****load-sharing liner**

liner which has a burst pressure greater than or equal to 5 % of the nominal burst pressure of the finished composite cylinder

**3.18**

**thermoplastic**

plastics capable of being repeatedly softened by increase of temperature and hardened by decrease of temperature

**3.19**

**thermosetting**

plastics that, when cured by the application of heat or chemical means, harden permanently into a substantially infusible and insoluble product

**3.20**

**working pressure**

$p_w$   
settled pressure, in bar, of a compressed gas at a reference temperature of 15 °C in a full gas cylinder

**3.21**

**nominal outside diameter**

diameter of the cylinder specified by the manufacturer for the type approval including tolerances (e.g.  $\pm 1\%$ )

**3.22**

**glass transition temperature**

T<sub>g</sub>  
the temperature where a polymer substrate changes from a rigid glassy material to a soft (not melted) material, and is usually measured in terms of the stiffness, or modulus.

## 4 Symbols

$p_{bl}$	burst pressure of finished liner	bar
$p_b$	burst pressure of finished cylinder	bar
$p_h$	test pressure	bar
$p_{max}$	maximum developed pressure at 65 °C	bar

## 5 Inspection and testing

To ensure that the cylinders conform to this document, they shall be subject to inspection and testing in accordance with [Clauses 6, 7, 8](#), and [9](#) by an inspection body (hereafter referred to as "the inspector") authorized to do so. Example forms of certificates that can be used are shown in [Annexes A](#) and [B](#).

Equipment used for measurement, testing, and examination during production shall be maintained and calibrated within a documented quality management system.

## 6 Materials

### 6.1 Liner materials

**6.1.1** The liner materials shall conform in all relevant respects to the appropriate standard:

- a) seamless steel liners: ISO 9809-1, ISO 9809-2 or ISO 9809-3, as appropriate;
- b) seamless stainless steel liners: ISO 9809-4;
- c) seamless aluminium alloy liners: ISO 7866.

Relevant clauses are those covering materials, thermal treatments, neck design, construction and workmanship, and mechanical tests. This excludes the design requirements since these are specified by the manufacturer for the design of the composite cylinder (see 7.2.2).

**6.1.2** The materials used shall be of uniform and consistent quality. The composite cylinder manufacturer shall verify that each new batch of materials has the correct properties and is of satisfactory quality. They shall also maintain records so that the cast of material and the heat treatment batch (where applicable) used for the manufacture of each cylinder can be identified.

**6.1.3** The liner shall be manufactured from a metal or alloy suitable for the gas to be contained in accordance with ISO 11114-1. For compatibility with hydrogen see ISO 11114-4.

**6.1.4** When a neck ring is provided, it shall be of a material compatible with that of the cylinder, and shall be securely attached by a method appropriate to the liner material.

## 6.2 Composite materials

**6.2.1** The overwrap materials shall be carbon fibre or aramid fibre or glass fibre or any mixture thereof.

**6.2.2** The matrix shall be a polymer suited to the application, environment, and intended life of the product.

**6.2.3** The supplier of the filament material and the matrix system component materials shall provide sufficient documentation for the composite cylinder manufacturer to be able to identify fully the batch of materials used in the manufacture of each cylinder.

**6.2.4** The materials used shall be of uniform and consistent quality. The composite cylinder manufacturer shall verify that each new batch of materials has the correct properties and is of satisfactory quality, and maintain records from which the batch of materials used for the manufacture of each cylinder can be identified. A certificate of conformity from the material manufacturer is considered acceptable for the purposes of verification.

**6.2.5** Batches of materials shall be identified and documented.

## 7 Design and manufacture

### 7.1 General

**7.1.1** A type 3 fully-wrapped composite gas cylinder with load-sharing liner shall comprise:

- a) an internal metal liner, which carries part of the longitudinal and circumferential load;
- b) a composite overwrap formed by layers of continuous fibres in a matrix;
- c) an optional external protection system.

Where necessary, care shall be taken to ensure that there is no adverse reaction between the liner and the reinforcing fibre by the application of a suitable protective coating to the liner prior to the wrapping process.

**7.1.2** Cylinders shall be designed with one or two openings along the central axis only. Threads shall extend completely through the neck or have sufficient threads to allow full engagement of the valve.

The cylinder can also include additional parts (e.g. neck rings, bases).

**7.1.3** The cylinders shall be designed for high reliability under sustained load and cyclic loading. Therefore, it is necessary to take account of the properties of the individual composite fibres and to establish their respective minimum fibre stress ratios.

The fibre stress ratio is defined as the fibre stress at calculated design minimum burst pressure divided by the fibre stress at 2/3 test pressure.

The minimum fibre stress ratios shall be as follows:

- for glass: 3,6;
- for aramid: 3,1;
- for carbon: 2,4.

The strength of the individual types of fibres used in hybrid construction may be verified by 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 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, then one of the reinforcing fibres shall be capable of meeting the stress ratio requirements even if all other fibre reinforcing materials are removed.

**7.1.4** Examples of certificates are shown in [Annexes A](#) and [B](#).

## 7.2 Design submission

**7.2.1** The design submission for each new design of cylinder shall include a detailed drawing, along with documentation of the design including manufacturing and inspection particulars as detailed in [7.2.2](#), [7.2.3](#), and [7.2.4](#).

**7.2.2** Documentation for the liner shall include (but not be limited to):

- a) material, including limits of chemical analysis;
- b) dimensions, minimum thickness, straightness, and out-of-roundness, with tolerances;
- c) process and specification of manufacture;
- d) heat treatment, temperatures, duration, and tolerances;
- e) inspection procedures (minimum requirements);
- f) material properties including minimum mechanical properties and hardness ranges, where applicable;
- g) minimum design burst pressure;
- h) dimensional details of valve threads and any other permanent features.

**7.2.3** Documentation for the composite overwrap shall include (but not be limited to):

- a) fibre material, specification, and mechanical properties requirements;
- b) minimum composite thickness;
- c) thermosetting matrix: specifications (including resin, curing agent and accelerator), and resin bath temperature where applicable;

- d) thermoplastic matrix system: main component materials, specifications and process temperatures;
- e) overwrap construction including the number of strands used, number of layers, layer orientation, and tensioning of the fibre at wrapping (where applicable);
- f) curing process, temperatures, duration, and tolerances, where applicable.

**7.2.4** Documentation for the composite cylinder shall include (but not be limited to):

- a) nominal water capacity, in litres, under ambient conditions;
- b) dimensions with tolerances
- c) list of intended contents, if intended for dedicated gas service;
- d) test pressure,  $p_h$ ;
- e) working pressure,  $p_w$  (if applicable), that shall not exceed  $0,67 \times p_h$ ;
- f) maximum developed pressure at  $65^\circ\text{C}$  for specific dedicated gas(es),  $p_{\max}$ ;
- g) minimum design burst pressure;
- h) design life in years, although cylinders with a test pressure of less than 60 bar shall have a non-limited design life;
- i) autofrettage pressure and approximate duration (where applicable);
- j) nominal mass of the finished composite cylinder, including tolerances;
- k) details of components which are permanently attached and form part of the qualified design (neck rings, protective boots, etc.).

### 7.3 Manufacturing

**7.3.1** The liner shall be manufactured in accordance with the manufacturer's design (see [7.2.2](#)) and the International Standard for the relevant metallic material (as listed in [6.1.1](#)).

**7.3.2** The composite cylinder shall be fabricated from a load-sharing liner fully overwrapped with layers of continuous fibres in a matrix applied under a controlled tension to develop the design composite thickness specified in [7.2.3](#).

Liners can be stripped and re-wound provided that the overwrap has not been cured. The liner shall not be overwrapped if it has been damaged or scored by the stripping process.

**7.3.3** After wrapping is completed the composite shall be cured (if appropriate) using a controlled temperature profile as specified in [7.2.3](#). The maximum temperature shall be such that the mechanical properties of the liner material are not adversely affected.

**7.3.4** If cylinders are subjected to an autofrettage operation, the autofrettage pressure and duration shall be as specified in [7.2.4](#). The manufacturer shall demonstrate the effectiveness of the autofrettage by appropriate measurement technique(s) acceptable to the inspector.

**7.3.5** If cylinders are subjected to a prestressing or fibre tensioning during wrapping in order to actively change the final stresses in the finished cylinder, the level of stress shall be as specified in the documentation in [7.2.4](#) and levels of stress of tensioning shall be recorded or monitored.

## 8 Type approval procedure

### 8.1 General requirements

Each new cylinder design shall be submitted by the manufacturer to the inspector. The type approval tests detailed in [8.2](#) shall be performed, under the supervision of the inspector, on each new cylinder design or design variant.

### 8.2 Prototype tests

**8.2.1** A minimum of 30 cylinders of the new design shall be made available for prototype testing. Upon successful completion of all prototype tests, the remaining untested cylinders from the prototype qualification batch can be used for service.

**8.2.2** If, for special applications, the total number of cylinders required is less than 30, sufficient cylinders shall be made to complete the prototype tests required, in addition to the production quantity. In this case, the approval validity is limited to this batch only.

For a limited design change (design variant), in accordance with [Table 1](#), a reduced number of cylinders shall be selected by the inspector.

**8.2.3** The batch of liners, prior to being wrapped, shall conform to the design requirements and shall be inspected and tested in accordance with [9.1](#).

**8.2.4** The composite material(s), prior to the cylinders being wrapped, shall conform to the design requirements and shall be tested in accordance with [9.3](#).

**8.2.5** Tests for a new cylinder design shall be supervised by an inspector and shall consist of:

- a) hydraulic proof pressure test, in accordance with [8.5.1](#) or, hydraulic volumetric expansion test, in accordance with [8.5.2](#);
- b) liner burst test, in accordance with [8.5.3](#);
- c) cylinder burst test, in accordance with [8.5.4](#);
- d) ambient temperature cycle test, in accordance with [8.5.5](#);
- e) environmental cycle test, in accordance with [8.5.6](#);
- f) flaw test, in accordance with [8.5.7](#);
- g) drop/impact test, in accordance with [8.5.8](#);
- h) high velocity impact (gunfire) test, in accordance with [8.5.9](#);

**8.2.6** Tests that are optional depending upon the design and intended use of the cylinder are:

- a) fire resistance test, in accordance with [8.5.10](#);
- b) salt water immersion test, in accordance with [8.5.11](#) (mandatory for underwater uses);
- c) environmentally assisted stress rupture test, in accordance with [8.5.13](#) (mandatory for cylinders with load sharing glass or aramid fibre);
- d) torque test, in accordance with [8.5.12](#).

**8.2.7** For approval of a design variant as specified in [8.4](#), it is only necessary to carry out the tests as stated in [Table 1](#) under supervision of the inspector. A cylinder approval by a reduced series of tests shall not be used as a basis for a second design variant approval with a reduced set of tests (i.e. multiple changes from an approved design are not permitted), although individual test results can be used as applicable (see [8.4.2](#)).

**8.2.8** Tests can be combined such that one cylinder can be used for more than one test. For example, the cylinder burst test in the drop/impact test ([8.5.8](#)) can be used to satisfy the requirement of the burst test ([8.5.4](#)).

**8.2.9** If the results of the above prototype tests are satisfactory, the inspector shall issue a type approval certificate, a typical example of which is given in [Annex A](#).

**8.2.10** After completion of the tests, the cylinders shall be destroyed or made incapable of holding pressure.

### 8.3 New design

**8.3.1** This clause specifies when a composite cylinder is a new design for the purposes of this document. Subclause [8.4](#) specifies when a composite cylinder is a design variant.

**8.3.2** A new cylinder design requires full type approval testing. A cylinder shall be considered to be of a new design compared with an existing approved design if:

- a) It is manufactured in a different factory. A relocation of a factory does not require a new cylinder design approval provided all equipment and procedures remain the same as for the original design approval.
- b) It is manufactured by a process that is significantly different from the process used in the design type approval. A significant change is regarded as a change that would have a measurable change in the performance of the liner and/or finished cylinder. The inspector shall determine when a change in process or design or manufacture is significantly different from the original qualified design.
- c) The nominal outside diameter has changed more than 50 % from the qualified design.
- d) A fibre of the same specification classification and mechanical properties, but with a different linear density shall not be considered a new fibre type. Changes in the wrapping pattern shall be considered to be a design variant [see [8.4.1 g](#)].
- e) The cylinder is manufactured with a new fibre type. A fibre shall be considered to be of a new fibre type when:
  - 1) the fibre is of a different classification (e.g. glass, aramid or carbon);
  - 2) the fibre is produced from a different precursor [e.g. polyacrylonitrile (PAN) or pitch for carbon];
  - 3) the fibre is not equivalent [see [8.4.1 i](#)] to the fibre in the original design
- f) The matrix materials (i.e. resin, curing agent, accelerator) are different and not chemically equivalent to the original design (e.g. a change from an epoxy to a polyester).
- g) The test pressure has increased more than 60 % from the qualified design.

**8.3.3** A cylinder shall also be considered to be of a new design compared with an existing approved design if the liner method of manufacture or design has changed to a significant extent.

**EXAMPLE 1** It is manufactured in a different factory. A relocation of a factory does not require a new cylinder design approval provided all equipment and procedures remain the same as for the original design approval.

EXAMPLE 2 It is manufactured from a material of different composition or composition limits from that used in the original type tests.

EXAMPLE 3 The material properties are outside the original design limits.

## 8.4 Design variants

**8.4.1** For cylinders similar to an approved design, a reduced type approval testing programme is required as specified in [Table 1](#). A cylinder shall be considered to be a design variant if changes are limited to the following:

- a) The nominal length of the cylinder has changed by more than 5 %.
- b) The nominal outside diameter has changed by 50 % or less.
- c) The autofrettage pressure has changed by more than 5 % or 10 bar, whichever is the lower.
- d) There is a change in the design test pressure up to and including 60 %.

NOTE Where a cylinder is to be used and marked for a lower test pressure than that for which design approval has been given, it is not deemed to be of a new design or design variant.

- e) The base profile and/or base thickness of the liner has changed relative to the cylinder diameter and minimum wall thickness and outside the tolerances provided in the design submission.
- f) The minimum wall thickness of the liner has changed by more than 5 %.
- g) There have been changes to the composite thickness outside the tolerances provided in the design submission.
- h) When equivalent matrix materials are used.

Epoxy, vinyl ester, and polyester systems are not chemically equivalent to each other, but two epoxy-based systems would be considered chemically equivalent as long as the minimum requirements of interlaminar shear testing are achieved and has a glass transition temperature  $T_g$  equal to or higher than the system being replaced. When equivalent overwrapping fibres are used.

- i) When equivalent overwrapping fibres are used.

Equivalent fibres are manufactured from the same nominal raw materials, using the same process of manufacture and having the same physical structure and the same nominal physical properties, and where the average tensile strength and modulus is within  $\pm 5$  % of the fibre properties in an approved cylinder design. Carbon fibres made from the same precursor can be equivalent. Aramid, carbon and glass fibres are not equivalent.

Where a new equivalent fibre has been prototype tested for an existing design, then all the manufacturer's existing prototype tested designs are regarded as prototype tested with the new fibre without the need for any additional prototype testing.

- j) When an equivalent liner is used:

- 1) equivalent liners are manufactured from the same nominal raw materials, using the same process of manufacture and having the same physical structure and where the average tensile strength and modulus is within  $\pm 5$  % of the approved cylinder design;
- 2) the equivalent liner material shall be subjected to the material tests specified in [9.1.3](#) and the liner burst test specified in [8.5.3](#) and in both cases shall meet the minimum requirements specified in [7.2.2](#);

- 3) where a new equivalent liner has been prototype tested for an existing design, then all the manufacturer's existing prototype tested designs are regarded as prototype tested with the new liner without the need for any additional prototype testing.
- k) When the cylinder thread has changed:

When a cylinder design has only a different thread compared to an approved design, only the torque test, in accordance with [8.5.12](#), shall be performed.

**8.4.2** A cylinder approval by a reduced series of tests (a "design variant") shall not be used as a basis for a second design variant approval with a reduced set of tests (i.e. multiple changes from an approved design are not permitted). If a test has been conducted on a design variant (A) that falls within the testing requirements for a second variant (B), then the result for (A) can be applied to the new design variant (B) test programme. However, design variant (A) cannot be used as the reference for determining the testing required for any new design variant.

**8.4.3** Where a design variant involves more than one parameter change all the tests required by those parameter changes shall be performed once only.

**8.4.4** The inspector shall determine the level of reduced testing if not defined in [Table 1](#), but a fully approved design shall always be used as a reference for the new design variant (i.e. new design variants shall not be approved by reference only to a previous design variant).

**8.4.5** Annex C is an example of a certificate that can be used to document the testing of liner materials and/or composite materials to prove equivalency with approved materials from a previous type approval

Table 1 — Type approval tests

Test No.	Test	New design	Nominal length	Nominal diameter				Design variant changes			
				$\leq 20\%$	$>20\%$	$\leq 50\%$	$>50\%$	Liner thickness change	Test pressure	Composite thickness	Liner base form
<b>9.1</b>	Liner material test	x				x	x				
<b>8.5.14</b>	Resin shear test	x									x
<b>9.3</b>	Overwrap material tests	x									x
<b>8.5.1</b>	Proof test or Hydraulic volumetric expansion test	x	x	x	x	x	x	x	x	x	x
<b>8.5.2</b>											
<b>8.5.3</b>	Liner burst	x	x	x	x	x	x	x	x	x	x
<b>8.5.4</b>	Hydraulic burst	x	x	x	x	x	x	x	x	x	x
<b>8.5.5</b>	Ambient cycle	x	x	x	x	x	x	x	x	x	x
<b>8.5.6</b>	Environmental cycle	x									x
<b>8.5.7</b>	Flaw	x									
<b>8.5.8</b>	Drop/impact	x	x	x	x	x	x <sup>b</sup>	x <sup>b</sup>	x <sup>b</sup>	x <sup>b</sup>	x
<b>8.5.9</b>	High velocity impact	x									
<b>8.5.10</b>	Fire resistance <sup>a</sup>	x	x	x	x	x	x <sup>b</sup>	x <sup>b</sup>	x <sup>b</sup>	x <sup>b</sup>	x
<b>8.5.11</b>	Salt water <sup>a</sup>	x									
<b>8.5.12</b>	Torque test <sup>d</sup>	x									
<b>8.5.13</b>	Stress rupture test <sup>a</sup>	x									
<b>8.5.15</b>	Glass transition temp	x									x

<sup>a</sup> Optional test required according to the design and intended use of the cylinder.

<sup>b</sup> Conducted with a liner or composite thickness decrease only.

<sup>c</sup> Test to be conducted for reduction in diameter only.

<sup>d</sup> When a cylinder design has only a different thread compared to an approved design only the torque test, in accordance with 8.5.12 shall be performed.

## 8.5 Type approval test procedures and criteria

### 8.5.1 Proof pressure test

#### 8.5.1.1 Procedure

When carrying out the pressure test, a suitable fluid shall be used as the test medium. This can include liquids such as water or oil and gases such as air or nitrogen). This test requires that the pressure in the cylinder be increased gradually and regularly until the test pressure,  $p_h$ , is reached. For cylinders up to 150 l the cylinder test pressure shall be held for at least 30 s with the cylinder isolated from the pressure source. For tubes of 150 l and above, the cylinder test pressure shall be held for at least 120 s with the cylinder isolated from the pressure source. During this time, there shall be no decrease in the recorded pressure (other than due to temperature variation of the test medium) or evidence of any leakage. Adequate safety precautions shall be taken during the test.

If leakage occurs in the piping or fittings, the cylinders shall be re-tested after repairing such leakages.

Where cylinders are subjected to autofrettage, the proof pressure test can immediately follow the autofrettage process.

The limit deviation on attaining test pressure shall be test pressure ( $p_h + 3$ ) % or  $(p_h + 10)_0$  bar, whichever is the lower. Pressure gauges with the appropriate accuracy shall be used.

All internal surfaces of cylinders shall be dried (to ensure no free water) immediately after testing.

Alternatively, a pneumatic pressure test can be used provided that appropriate measures are taken to ensure safe operation and to contain any energy that can be released, which is considerably more than in the hydraulic test.

#### 8.5.1.2 Criteria

The cylinder shall be rejected if there are leaks, failure to hold pressure or visible permanent deformation after the cylinder is depressurized.

NOTE Cracking of resin is not necessarily a sign of permanent deformation.

### 8.5.2 Hydraulic volumetric expansion test

#### 8.5.2.1 Procedure

When carrying out the pressure test, a suitable fluid (normally water) shall be used as the test medium. This test requires that the pressure in the cylinder be increased gradually and regularly until the test pressure,  $p_h$ , is reached. For cylinders up to 150 l the cylinder test pressure shall be held for at least 30 s with the cylinder isolated from the pressure source. For tubes of 150 l and above, the cylinder test pressure shall be held for at least 120 s with the cylinder isolated from the pressure source. During this time there shall be no decrease in the recorded pressure or evidence of any leakage. Adequate safety precautions shall be taken during the test.

If leakage occurs in the piping or fittings, the cylinders shall be re-tested after repairing such leakages.

The total volumetric expansion of each cylinder under the test pressure,  $p_h$ , and the permanent volumetric expansion of the cylinder after the pressure is released shall be recorded. The elastic expansion (i.e. total expansion less permanent expansion) under test pressure shall then be established for each cylinder.

Where cylinders are subjected to autofrettage, the hydraulic volumetric expansion pressure test can immediately follow the autofrettage process.

The limit deviation on attaining test pressure shall be  $(p_h + 3) \%$  or  $(p_h + 10) \text{ bar}$ , whichever is the lower. All internal surfaces of cylinders shall be dried (to ensure no free water) immediately after testing.

### 8.5.2.2 Criteria

The cylinder shall be rejected if:

- a) there are leaks or failure to hold pressure;
- b) there is permanent expansion (i.e. volumetric expansion after the pressure has been released) in excess of 5 % of the total expansion.

### 8.5.3 Liner burst test

#### 8.5.3.1 Procedure

One liner shall be tested hydraulically to destruction by pressurizing at a rate of no more than 5 bar/s. The test shall be carried out under ambient conditions.

The parameters that shall be monitored and recorded are:

- a) burst pressure;
- b) the number of pieces;
- c) description of failure;
- d) pressure-time curve or pressure-volume curve.

#### 8.5.3.2 Criteria

The burst pressure,  $p_{bl}$ , shall be not less than the minimum design burst pressure specified in the design submission (7.2.2). Failure shall initiate in the liner side wall and the liner shall remain in one piece.

### 8.5.4 Cylinder burst test

#### 8.5.4.1 Procedure

Three cylinders shall be tested hydraulically to destruction by pressurizing at a rate of no more than 10 bar/s. The test shall be carried out under ambient conditions. Prior to the commencement of the test, it shall be ensured that no air is trapped within the system.

The parameters that shall be monitored and recorded are:

- a) burst pressure;
- b) description of failure;
- c) pressure-time curve or pressure-volume curve.

#### 8.5.4.2 Criteria

- a) The burst pressure shall exceed the minimum design burst pressure specified by the cylinder manufacturer (see 7.2.4).
- b) The burst pressure,  $p_b$ , for cylinders with carbon fibre reinforcement shall be not less than  $2,0 \times p_h$ , where  $p_h$  is the test pressure.
- c) The burst pressure,  $p_b$ , for cylinders with aramid fibre reinforcement shall be not less than  $2,1 \times p_h$ .

d) The burst pressure,  $p_b$ , for cylinders with glass fibre reinforcement shall be not less than  $2,4 \times p_h$ .

### 8.5.5 Ambient cycle test

#### 8.5.5.1 For cylinders with test pressure equal to or greater than 60 bar

##### 8.5.5.1.1 General

Where a cylinder is intended for use only with one or more specific gases, the design can be designated for dedicated gas use. The gases permitted in the cylinder shall be identified clearly on the cylinder label (see 10.2). Cylinders tested to test pressure,  $p_h$ , or maximum developed pressure,  $p_{max}$ , shall have a specified design life from 15 years to non-limited life.

##### 8.5.5.1.2 Procedure

Two cylinders shall be subjected to a hydraulic pressure cycle test to either:

- a) test pressure,  $p_h$ , for unspecified gas service; or
- b) maximum developed pressure at 65 °C,  $p_{max}$ , for the dedicated gas which has the greatest developed pressure;

The test shall be carried out using a non-corrosive fluid under ambient conditions, subjecting the cylinders to successive reversals at an upper cyclic pressure which is equal to the hydraulic test pressure,  $p_h$ , or maximum developed pressure at 65 °C,  $p_{max}$ , as appropriate.

The value of the lower cyclic pressure shall not exceed 10 % of the upper cyclic pressure, but shall have an absolute maximum of 30 bar. The frequency of reversals of pressure shall not exceed 0,25 Hz (15 cycles per minute). The temperature on the outside surface of the cylinder shall not exceed 50 °C during the test.

The parameters that shall be monitored and recorded are:

- a) the temperature of the cylinder;
- b) number of cycles achieving upper cyclic pressure;
- c) minimum and maximum cyclic pressures;
- d) cycle frequency;
- e) test medium used;
- f) mode of failure, if appropriate.

##### 8.5.5.1.3 Criteria

Both cylinders shall withstand  $N$  pressurization cycles to test pressure,  $p_h$ , or  $N_d$  pressurization cycles to maximum developed pressure,  $p_{max}$ , without failure by burst or leakage, as determined with [Formulae \(1\)](#) and [\(2\)](#):

- $N$  pressurization cycles to test pressure,  $p_h$ , or
- $N_d$  pressurization cycles to maximum developed pressure,  $p_{max}$ ;

where

$$N = t \times 250 \quad (1)$$

$$N_d = t \times 500 \quad (2)$$

where  $t$  is the number of years of design life, which shall be a whole number, not less than 15.

The test shall continue for a further  $N$  or  $N_d$  cycles, or until the cylinder fails by leakage, whichever is the sooner. In either case, the cylinder shall be deemed to have passed the test. However, if failure during this second part of the test is by burst, then the cylinder shall have failed the test (see [Table 2](#)).

If the cylinder is designed to pass 12 000 hydraulic cycles to test pressure or 24 000 cycles to maximum developed pressure, and achieves this level in the test it is not necessary to limit the design life of the cylinder.

**Table 2 — Criteria for the ambient cycle test**

	<b>First part</b>	<b>Second part</b>
Number of cycles	0 to $N$	$N$ to $2N$ but $2N$ no more than 12 000
	0 to $N_d$	$N_d$ to $2N_d$ but $2N_d$ no more than 24 000
Criteria	No leakage/burst = Pass	
	No leakage or burst	Leakage = Pass
	Pass first part	Burst = Fail

### 8.5.5.2 For cylinders with test pressure less than 60 bar

#### 8.5.5.2.1 Procedure

Two cylinders shall be subjected to a hydraulic pressure cycle test to test pressure.

The test shall be performed using a non-corrosive fluid under ambient conditions, subjecting the cylinders to successive reversals at an upper cyclic pressure which is equal to the hydraulic test pressure,  $p_h$ .

The value of the lower cyclic pressure shall not exceed 10 % of the upper cyclic pressure. The frequency of reversals of pressure shall not exceed 0,25 Hz (15 cycles per minute). The temperature on the outside surface of the cylinder shall not exceed 50 °C during the test.

The following parameters shall be monitored and recorded:

- the temperature of the cylinder;
- number of cycles achieving upper cyclic pressure;
- minimum and maximum cyclic pressures;
- cycle frequency;
- test medium used;
- mode of failure, if appropriate.

#### 8.5.5.2.2 Criteria

Both cylinders shall withstand 12 000 pressurization cycles to test pressure,  $p_h$ . If the cylinder is designed to pass 12 000 hydraulic cycles to test pressure and achieves this level consistently in the test it is not necessary to limit the design life of the cylinder.

## 8.5.6 Environmental cycle test

### 8.5.6.1 General

Perform the tests in this clause in an environmental chamber. One cylinder, without paint or removable protective coating and/or casing shall be tested.

### 8.5.6.2 Procedure

The cylinder to be tested shall be filled at the ambient atmospheric pressure using a suitable medium (e.g. a non-corrosive fluid) such that its properties do not degrade from those at ambient temperature when used at the test temperature extremes.

Condition cylinder and contained pressurizing medium for 48 h at atmospheric pressure, at a temperature between 60 °C and 70 °C and at a relative humidity greater than or equal to 90 %. The intent of this requirement can be met by spraying with a continuous fine spray or mist of water in a chamber held between 60 °C and 70 °C.

Then install the cylinder to be tested in an environmental chamber capable of meeting the temperature and humidity requirements for the test.

Connect the cylinder to be tested to a source of pressure, mounted externally to the environmental chamber, which can meet the cylinder pressure cycling requirements.

Seal the cylinder in the environmental test chamber and follow a) to c).

- a) Carry out the hot cycle test phase starting with the cylinder at ambient temperature, pressure, and humidity. Change the test chamber environment until a cylinder surface temperature of between 60 °C and 70 °C is achieved. Cycle the internal pressure between  $0,67 \times p_h$  and less than 10 % of the working pressure (6,67 % of the test pressure) for 5 000 cycles using the external pressurizing medium supplied at ambient temperature.

The cycling frequency shall not exceed 5 cycles per minute.

During the test, the cylinder surface temperature shall be maintained at between 60 °C and 70 °C (e.g. by regulating the environmental chamber parameters and the pressure cycling frequency).

Once the required number of pressure cycles has been completed, release the cylinder internal pressure and stabilize its temperature at approximately 20 °C.

- b) Carry out the cold cycle test phase starting the cylinder at ambient atmospheric temperature, pressure and humidity. Change the test chamber environment until a cylinder surface temperature of between -50 °C and -60 °C is achieved. Cycle the internal less than 10 % of working pressure (6,67 % of test pressure) and  $0,67 \times p_h$  for 5 000 cycles using the external pressurizing medium supplied at ambient temperature.

The cycling frequency shall not exceed 5 cycles per minute.

During the test, the cylinder surface temperature shall be maintained at between -50 °C and -60 °C (e.g. by regulating the environmental chamber parameters and the pressure cycling frequency).

Once the required number of pressure cycles has been completed, release the cylinder internal pressure and stabilize its temperature at approximately 20 °C.

- c) Carry out a burst test in accordance with 8.5.4.

The parameters that shall be monitored and recorded are:

- 1) the cylinder surface temperature throughout the test;
- 2) the test chamber humidity;

- 3) the cylinder pressurization medium used;
- 4) the number of pressure cycles completed (a complete cycle achieves the required test pressure, e.g.  $p_{\max d}$ );
- 5) the minimum and maximum cyclic pressures achieved for each test cycle;
- 6) the pressure cycle frequency;
- 7) the parameters specified in [8.5.4](#).

#### 8.5.6.3 Criteria

- a) The burst pressure,  $p_b$ , for cylinders with carbon fibre reinforcement shall be not less than  $1,7 \times p_h$ .
- b) The burst pressure,  $p_b$ , for cylinders with aramid fibre reinforcement shall be not less than  $1,9 \times p_h$ .
- c) The burst pressure,  $p_b$ , for cylinders with glass fibre reinforcement shall be not less than  $2,2 \times p_h$ .

#### 8.5.7 Flaw test

##### 8.5.7.1 Procedure

Two cylinders shall be tested. One longitudinal flaw shall be cut into each cylinder, in the mid-length of the cylindrical wall of the cylinder in accordance with [Figure 1](#). The flaw shall be made with a 1 mm thick cutter to a depth equal to at least 50 % of the composite thickness (t) (measured from the outside surface of the finished cylinder), but no greater than 2,5 mm deep, and to a length between the centres of the cutter equal to five times the composite thickness (t).

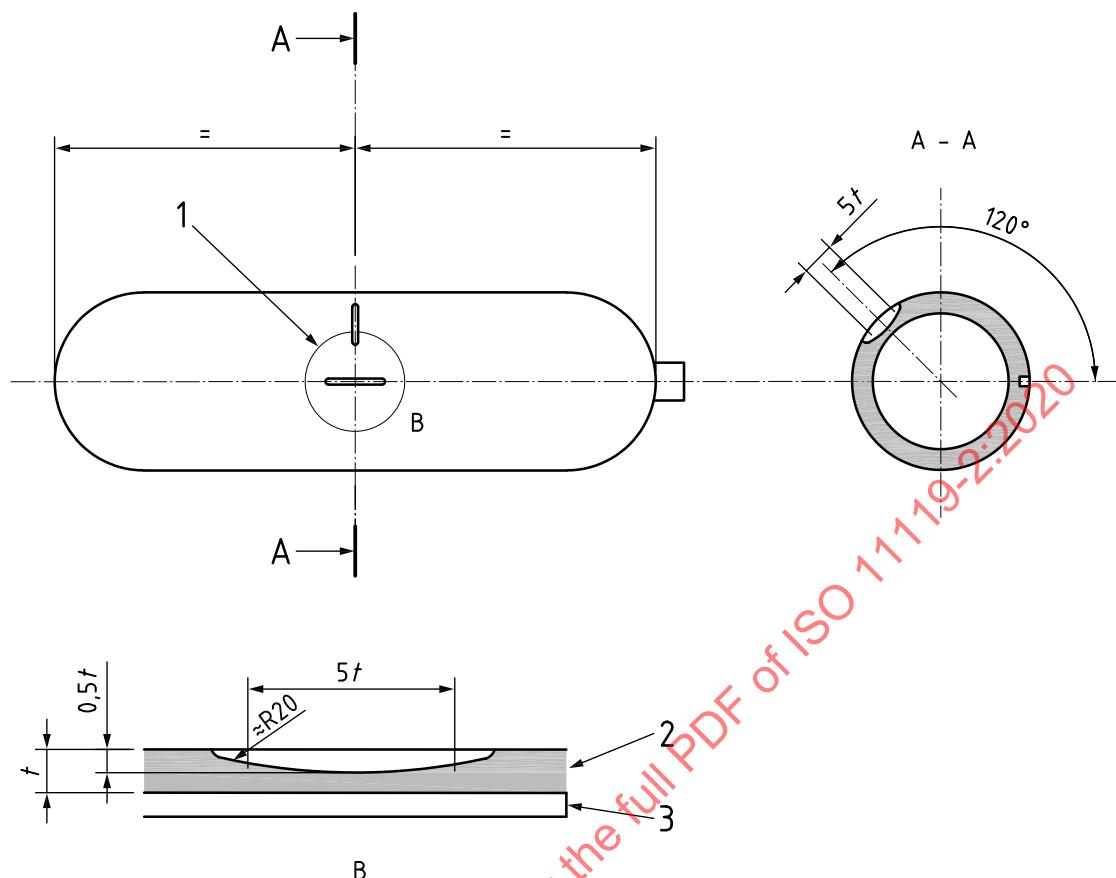
A second transverse flaw of the same dimensions shall be cut into each cylinder in the mid-length of the cylindrical wall approximately 120° around the circumference from the other flaw in accordance with [Figure 1](#).

One cylinder shall be subjected to the burst test specified in [8.5.4](#).

The other cylinder shall be subjected to the pressure cycling test in [8.5.5](#), but the upper cyclic pressure shall be  $0,67 \times p_h$  and the test shall be suspended after 5 000 cycles if the cylinder has not failed.

The parameters that shall be monitored and recorded are:

- a) dimensions of flaws;
- b) the temperature of the cylinder;
- c) number of cycles achieving upper cyclic pressure;
- d) minimum and maximum cyclic pressures;
- e) cycle frequency;
- f) test medium used;
- g) mode of failure, if appropriate.

**Key**

- 1 flaw, 1 mm wide
- 2 wrap
- 3 liner

**Figure 1 — Flaw test procedure****8.5.7.2 Criteria**

First cylinder: Burst pressure,  $p_b$ , shall be greater than or equal to  $1,33 \times p_h$ .

Second cylinder: The cylinder shall withstand at least 1 000 pressure cycles to  $0,67 \times p_h$ , without leakage. If the cylinder fails by leakage after 1 000 cycles, it shall be deemed to have passed the test. However, if failure during this second half of the test is by burst, then the cylinder shall have failed the test.

**8.5.8 Drop/impact test****8.5.8.1 General**

The test procedure in 8.5.8.2 shall be used for cylinders up to and including 50 l water capacity with unspecified gas service and cylinders with dedicated liquefied gas service. The test procedure in 8.5.8.4 shall be used for cylinders over 50 l water capacity with unspecified gas service. The test procedure in 8.5.8.3 is an alternative test for cylinders up to and including 50 l water capacity used in designated compressed gas service.

The test procedure in 8.5.8.5 is an alternative to 8.5.8.4 for tubes of 150 l water capacity and above.

Where a cylinder is intended for use only with one or more specific gases, the design can be designated for dedicated gas use. The gases permitted in the cylinder shall be identified clearly on the cylinder label (see 10.2).

#### 8.5.8.2 For cylinders up to and including 50 l water capacity with unspecified gas service and cylinders with liquefied gas service

##### 8.5.8.2.1 Procedure

Two cylinders shall be filled with water to 50 % capacity and fitted with a steel or aluminium plug with diameter no greater than the neck diameter, to protect threads and sealing surfaces.

Both cylinders shall be dropped twice, in each of the five positions shown in Figure 2, from a minimum height of 1,2 m, onto a smooth concrete surface or a protective steel plate of a minimum of 10 mm thickness. The drop surface shall be sufficiently flat so that the difference in level between any two points on the surface is no more than 2 mm.

One cylinder shall be subjected to the burst test specified in 8.5.4.

The other cylinder shall be subjected to the pressure cycling test specified in 8.5.5.

The parameters that shall be monitored and recorded are the following:

- visual appearance after each drop: record position and dimensions of impact damage;
- parameters specified in test 8.5.4;
- parameters specified in test 8.5.5.

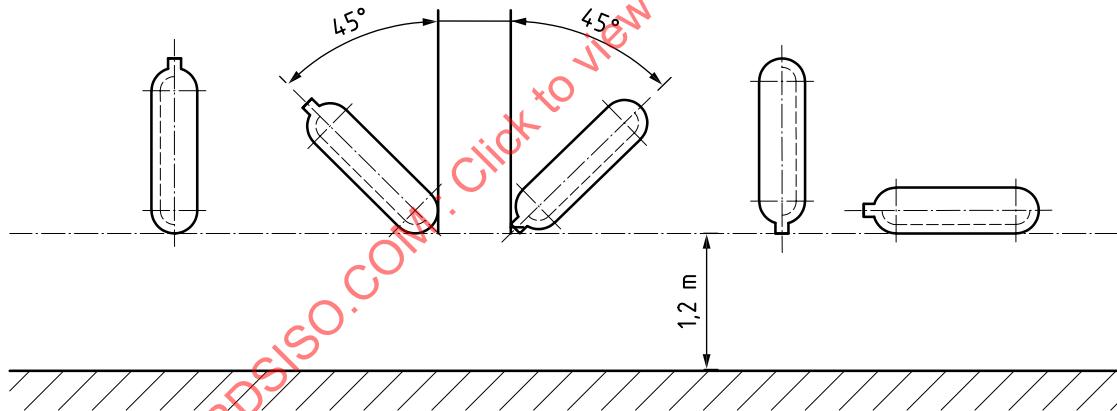


Figure 2 — Drop test

##### 8.5.8.2.2 Criteria

First cylinder: burst pressure,  $p_b$ , shall be equal to or greater than 100 % of the minimum burst level required in the burst test (see 8.5.4).

Second cylinder: the cylinder shall satisfy the requirements of the ambient cycle test (see 8.5.5).

#### 8.5.8.3 For cylinders up to and including 50 l water capacity with dedicated compressed gas service

##### 8.5.8.3.1 Procedure

Two cylinders shall be fitted with a steel or aluminium plug with diameter no greater than the neck diameter, to protect threads and sealing surfaces.

Both cylinders shall be dropped twice, in each of the five positions shown in [Figure 1](#), from the calculated drop height on to a smooth concrete surface or a protective steel plate of a minimum of 10 mm thickness. The drop surface shall be sufficiently flat so that the difference in level between any two points on the surface is no more than 2 mm.

The drop height,  $h$ , shall be calculated as per [Formula \(3\)](#):

$$h = 1,2 + (0,6 \times V/m) \quad (3)$$

where

$V$  is the water volume of the cylinder in litres;

$m$  is the weight of the empty cylinder in kilograms.

One cylinder shall be subjected to the burst test in [8.5.4](#).

The other cylinder shall be subjected to the pressure cycling test in [8.5.5](#).

The following parameters that shall be monitored and recorded are:

- visual appearance after each drop: record position and dimensions of impact damage;
- parameters specified in [8.5.4](#);
- parameters specified in [8.5.5](#).

#### 8.5.8.3.2 Criteria

First cylinder: burst pressure,  $p_b$ , shall be equal to or greater than 100 % of the minimum burst level required in the burst test (see [8.5.4](#)).

Second cylinder: the cylinder shall satisfy the requirements of the ambient cycle test (see [8.5.5](#)).

#### 8.5.8.4 For cylinders over 50 l water capacity

##### 8.5.8.4.1 Procedure

One or more empty cylinders, with sealing device to protect threads and sealing surfaces, shall be drop tested at ambient temperature. The surface onto which the cylinders are dropped shall be a smooth, horizontal concrete pad or flooring.

One cylinder shall be dropped in a horizontal position with the lowest point of the cylinder no less than 1,8 m above the surface onto which it is dropped. One cylinder shall be dropped vertically on one end at a sufficient height above the floor or pad so that the potential energy is 1 220 J, but the height of the lower end shall in no case be greater than 1,8 m. One cylinder shall be dropped at a 45° angle onto a dome from a height such that the centre of gravity is at 1,8 m. However, if the lower end is less than 0,6 m from the ground, the drop angle shall be changed to maintain a minimum height of 0,6 m and a centre of gravity of 1,8 m. The cylinder(s) shall be allowed to bounce on the concrete pad or flooring after the initial impact. No attempt shall be made to prevent this secondary impacting, but the cylinder can be prevented from toppling during the vertical drop test.

After completion of the drop the cylinder(s) shall be subjected to cycle testing at 2/3 of the test pressure,  $p_h$ , for 12 000 cycles.

##### 8.5.8.4.2 Criteria

The cylinders shall withstand 3 000 pressurization cycles to 2/3 of the test pressure,  $p_h$ , without failure by burst or leakage. The test shall continue for a further 9 000 cycles, or until the cylinder fails by leakage,

whichever is the sooner. In either case, the cylinder shall be deemed to have passed the test. However, if failure during this second part of the test is by burst, then the cylinder shall have failed the test.

#### 8.5.8.5 For tubes over 150 l water capacity

##### 8.5.8.5.1 Procedure

One or more empty tubes, with sealing device to protect threads and sealing surfaces, shall be impact tested at ambient temperature.

One empty tube and if necessary a second empty tube, shall be subjected to two impacts:

- a) one to strike the tube on one end;
- b) one at an angle of 45° to strike the shoulder of the tube (mid arc length at the dome).

See [Figure 3](#).

The impact can be conducted by dropping a suitable weight or by a pendulum impact.

The tube shall be secured to ensure it does not move during the impact. The impactor shall be made from a steel bar and have a diameter of between 110 and 120 mm.

Two levels of impact are permitted.

Test one — an impactor with a potential energy of 1 200 J shall strike the tube at the positions identified in [Figure 3](#).

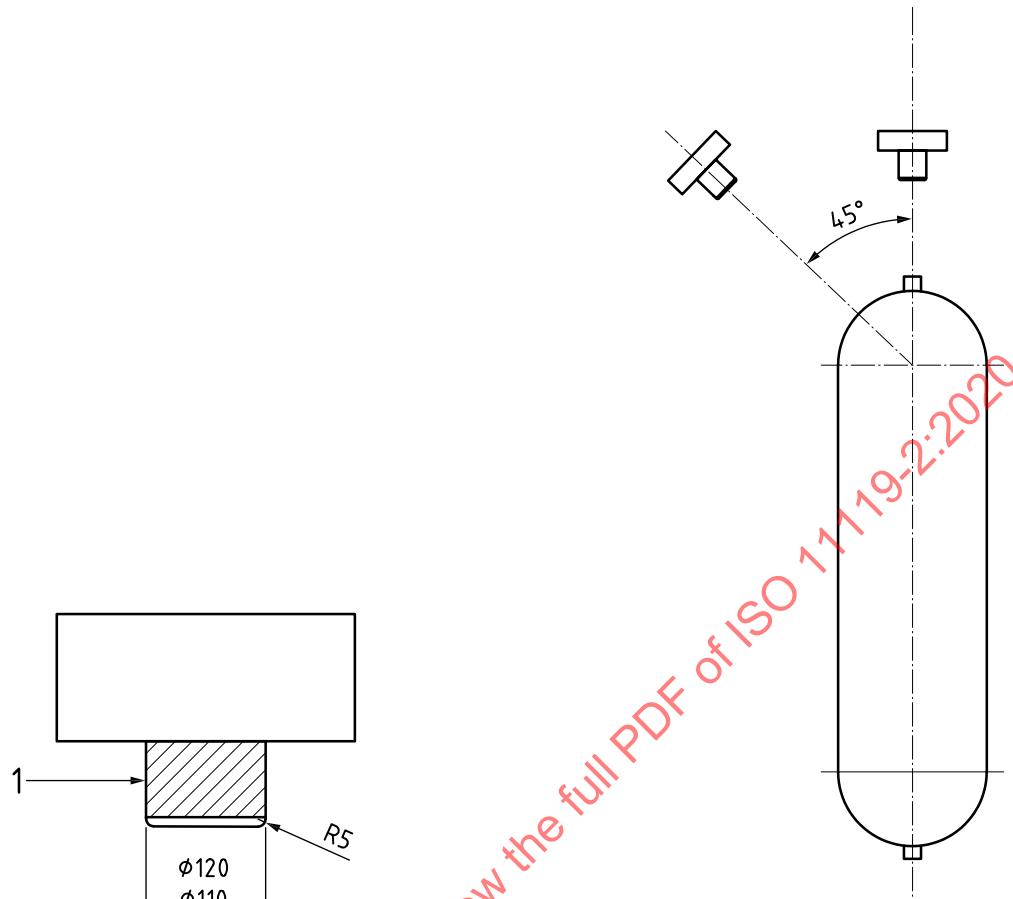
Test two — (if necessary) an impactor with a potential energy of 488 J shall strike the tube at the positions identified in [Figure 3](#).

After completion of the drop the tube(s) shall be subjected to cycle testing at 2/3 of the test pressure,  $p_h$ , for 12 000 cycles.

##### 8.5.8.5.2 Criteria

The tubes shall withstand 3 000 pressurisation cycles at maximum developed pressure  $p_{max}$  without failure by burst or leakage. The test shall continue for additional cycles representing its specified lifetime, or until the tube fails by leakage, whichever is the sooner. In either case the tube shall be deemed to have passed the test. However, if failure during this second part of the test is by burst, then the tube shall have failed the test.

A tube passing the test at an energy level of 1 200 J shall be identified as achieving impact resistance level 2, which shall be reported in the qualification report and on the label (see [10.2](#)). If the tube does not pass the blunt impact test at this level, a second tube shall be tested at an energy level of 488 J. A tube passing the test at an energy level of 488 J shall be identified as achieving impact resistance level 1, which shall be reported on the qualification report and on the label (see [10.2](#)). A tube that does not pass at an energy level of 488 J shall not be approved.



a) Example of impactor

Figure 3 — Impact test for tubes above 150 l

## 8.5.9 High velocity impact (gunfire) test

### 8.5.9.1 Procedure

One cylinder shall be filled to the working pressure ( $0,67 \times p_h$ ) with air or nitrogen or the gas to be contained.

**WARNING** — Appropriate measures shall be taken to ensure safe operation and to contain any energy that can be released.

The cylinder shall be positioned in such a way that the point of impact of the projectile is in the cylinder side wall at a nominal angle of 90°.

Cylinders with diameter of above 120 mm shall be impacted by a 7,62 mm (0,3 calibre) armour-piercing projectile (of length between 37 mm and 51 mm) with a nominal speed of about 850 m/s. The bullet shall be fired from a distance no more than 45 m. The cylinder shall be safely vented before removal from the test site.

Cylinders with diameter of 120 mm and below shall be impacted by a 5,6 mm armour-piercing projectile (or similar) with a nominal speed of 850 m/s. The bullet shall be fired from a distance of no more than 45 m. The cylinder shall be safely vented before removing from the test.

Alternatively, a non-armour-piercing projectile may be used provided that the projectile penetrates at least one cylinder side wall. The dimensions of the entrance and exit openings are measured and recorded.

The parameters that shall be monitored and recorded are:

- a) type of projectile;
- b) initial pressure;
- c) description of failure;
- d) approximate size of the entrance and exit openings.

#### **8.5.9.2 Criteria**

The cylinder shall remain in one piece. If a cylinder is not penetrated by an armour piercing projectile, then the cylinder will have passed the test.

If a non-armour piercing projectile is used, then the cylinder sidewall shall be penetrated, and the cylinder shall remain in one piece.

#### **8.5.10 Fire resistance test**

##### **8.5.10.1 General**

The purpose of the test is to demonstrate that the cylinder design shall either

- a) not burst when exposed to a test fire when using a specified pressure relief device, or
- b) will withstand a minimum specified time in the test fire when a pressure-relief device is not to be used in service.

This test is mandatory if pressure relief devices (PRDs) are fitted to prevent failure in case of fire in service and is optional for other uses. An optional fire resistance test for cylinders that will be fitted with thermal relief devices in service is shown in [Annex D](#).

##### **8.5.10.2 Procedure**

###### **8.5.10.2.1 General**

Two cylinders shall be fitted with either:

- a) the valves and PRDs intended for use (if known); or
- b) if a PRD is not intended to be used in service then a suitable method for pressure release after the test has been completed is required for safety purposes. This can include a remote-controlled valve, or a suitable valve fitted with a bursting disc or thermal relief device. If the test is conducted with the PRDs and valve intended for use in service [i.e. option a)], the specification of the valve and PRDs shall be marked on the design drawing and the approval certificate.

The cylinders shall be charged with air or nitrogen, or the gas intended for use to the working pressure ( $0,67 \times p_h$ ), or for LPG applications LPG filled to the maximum permissible filling ratio.

Cylinders less than or equal to 50 l water capacity shall be subjected to one horizontal and one vertical fire test. Cylinders with a water capacity greater than 50 l shall be subjected to two horizontal fire tests.

Any fuel can be used for the fire source provided it supplies uniform heat sufficient to maintain the specified test temperatures until the cylinder is vented. The selection of a fuel should take into consideration pollution concerns.

Timing of the test starts when a thermocouple reaches 590 °C and at least two thermocouples must register a minimum temperature of 590 °C for the remainder of the test. The cylinders shall be tested in the vertical or horizontal position as follows:

#### 8.5.10.2.2 Horizontal test

One cylinder shall be placed in a horizontal position with the centre of the fire at the mid-point of the cylinder and with the lowest part of the cylinder approximately 0,1 m from the top of the fire source. The relief device shall be shielded from the direct flame impingement.

Surface temperatures shall be monitored by thermocouples located along the bottom of the cylinders and spaced not more than 0,75 m apart and shielded from direct flame impingement with a metallic shielding of a minimum 0,4 mm thickness.

A uniform fire source of 1,65 m length that is capable of enveloping the entire diameter of the cylinder and producing a temperature of 590 °C or greater shall be used.

The cylinder shall be exposed to the fire until it has vented to a pressure less than 7 bar. After the test, the cylinder shall be rendered unserviceable.

#### 8.5.10.2.3 Vertical test

One cylinder shall be placed in an upright position (valve uppermost for cylinders with one valve and PRD), with the lowest part of the cylinder approximately 0,1 m from the top of the fire source. The relief device shall be shielded from direct flame impingement. For cylinders of 20 l water capacity or less, a fire source 1 m × 1 m shall be constructed. For cylinders having a water capacity greater than 20 l but not more than 50 l, a fire source 1,65 m × 1,65 m shall be constructed, and the cylinders oriented as described above. The fire source shall be capable of producing a temperature of 590 °C or greater.

Surface temperatures shall be monitored by thermocouples located at the following places on the cylinder: for a cylinder 30,5 cm length or less, one thermocouple at the top of the cylinder and one thermocouple at the base of the cylinder which shall be shielded from direct flame impingement with a metallic shielding of a minimum 0,4 mm thickness. For a cylinder with a length greater than 30,5 cm, an additional thermocouple shall be located at the mid-point of the cylinder's sidewall.

The cylinder shall be exposed to the fire until it has vented to a pressure less than 7 bar. After the test, the cylinder shall be rendered unserviceable.

The parameters that shall be monitored and recorded are:

- type and characteristics of pressure relief device;
- initial pressure;
- location of leak;
- temperature;
- time.

#### 8.5.10.3 Criteria

- For cylinders intended to be fitted with a specified pressure-relief device, the cylinders shall vent through the pressure-relief devices. (This test shall be repeated if another design of pressure-relief device is specified and used). Cylinders may also leak through the cylinder wall, other surfaces or devices (e.g. the valve).
- Cylinders without a specified pressure-relief device shall not burst during
  - a period of 2 min from the start of the fire test for cylinders up to 150 l.

- ii) a period of 5 min from the start of the fire test for cylinders 150 l and above.

Cylinders may vent through the pressure relief device or leak through the cylinder wall or other surfaces.

- c) For cylinders with test pressure below 60 bar and intended to be used to transport liquefied flammable gases (e.g. LPG), the cylinder shall not rupture during a period of 20 min. The gas may vent through the pressure-relief devices, the cylinder wall or other devices (e.g. valve) at any stage of the test.

### 8.5.11 Salt water immersion test

#### 8.5.11.1 General

This test is mandatory for all cylinders intended for underwater applications, but is not required for other applications.

#### 8.5.11.2 Procedure

The cylinders shall be unpainted, but otherwise finished as for the intended application. The liner can be painted or protected from corrosion in any manner that is included in the design submission.

##### a) Immersion period

Two closed unpressurized cylinders shall be immersed for a period of between 1 h and 2 h in an aqueous solution containing 35 g/l of sodium chloride at a temperature not less than 20 °C.

After 2 h the hydraulic pressure of the cylinder shall be increased to and maintained at  $0,67 \times p_h$  for not less than 22 h.

##### b) Drying period

The pressurized cylinders shall then be removed from the salt water and subjected to natural drying conditions in ambient atmosphere for not less than 22 h.

During this drying-out period, the cylinders shall be pressurized. The hydraulic pressure of the cylinder shall be increased to and maintained at  $0,67 \times p_h$  for not less than 2 h. Pressure shall then be released.

Repeat the cycle consisting of these two periods, a) and b), 45 times.

On completion of these tests, one of the two cylinders shall be submitted to the burst test in accordance with [8.5.4](#). The other cylinder shall be submitted to pressure cycling in accordance with [8.5.5](#).

The parameters that shall be monitored and recorded are:

- 1) the temperature of the solution, at least once a day;
- 2) filling pressure;
- 3) duration of immersion;
- 4) parameters specified in test [8.5.4](#);
- 5) parameters specified in test [8.5.5](#).

#### 8.5.11.3 Criteria

- a) The burst pressure,  $p_b$ , shall be not less than the burst pressure in [8.5.4](#) for the relevant fibre.
- b) The second cylinder shall satisfy the criteria for the ambient cycle test, [8.5.5](#).

## 8.5.12 Torque test

### 8.5.12.1 General

This test is only applicable to cylinders with taper threads.

### 8.5.12.2 Procedure

The body of the cylinder shall be held in a manner to prevent it rotating. The cylinder shall be fitted with a corresponding valve or threaded plug and tightened to 110 % of the maximum torque recommended in ISO 13341 for the relevant liner material or as recommended by the manufacturer where ISO 13341 does not apply.

The parameters that shall be monitored and recorded are:

- a) type of valve and plug material;
- b) valving procedure;
- c) applied torque.

### 8.5.12.3 Criteria

The cylinder neck and threads shall remain within drawing and gauge tolerance.

## 8.5.13 Environmentally assisted stress rupture test

### 8.5.13.1 Procedure

This test shall be conducted only on cylinders where glass or aramid fibre has a load-sharing application.

For a design life of up to 20 years, two cylinders shall be hydraulically pressurized to test pressure,  $p_h$ , and maintained at this pressure for 1 000 h. For a design life equal to or greater than 20 years, the test shall run for 2 000 h. The test shall be conducted at a minimum temperature of  $70\text{ }^\circ\text{C} \pm 5\text{ }^\circ\text{C}$  and a relative humidity greater than or equal to 95 %. Use of a water spray or suspending the cylinder over water bath meets the requirements of this test.

After this test, the cylinders shall be subjected to the burst test (see [8.5.4](#)).

The parameters that shall be monitored and recorded are:

- a) temperature and relative humidity at least twice a day;
- b) cylinder pressure at least twice a day;
- c) burst pressure.

### 8.5.13.2 Criteria

The cylinder shall not exhibit any visible deformation or loose fibres (unravelling) and the burst pressure,  $p_b$ , shall be greater than or equal to 100 % of the minimum burst level required in the burst test ([8.5.4](#)) for the relevant fibre.

## 8.5.14 Resin shear strength

Matrix materials shall be tested on a sample coupon representative of the composite overwrap in accordance with ISO 14130 or equivalent. This test shall be repeated when matrix materials are changed from the matrix materials in the original design.

NOTE Interlaminar shear testing should be conducted the same conditions using the same size test specimen.

Following immersion for 24 h in boiling water the composite shall have a minimum shear strength of 13,8 MPa.

#### 8.5.15 Glass transition temperature

The glass transition temperature of the matrix materials shall be tested in accordance with ASTM E1356 – 08 or an equivalent standard. This test shall be repeated when matrix materials are changed from the matrix materials in the original design.

The matrix materials shall meet the minimum glass transition temperature specified by the cylinder manufacturer.

### 8.6 Failure of type approval tests

In the event of failure to meet test requirements, an investigation into the cause of failure and re-testing shall be carried out in accordance with [9.5](#).

## 9 Batch inspection and testing

### 9.1 Liner

**9.1.1** Each batch of liners shall be examined and dimensionally checked to ensure compliance with the design specification. The inspections to be carried out in accordance with the manufacturer's quality assurance procedures are listed in a) to f):

- a) visual inspection of surface finish;
- b) dimensions;
- c) neck folds: interior folding in the liner neck area shall be prohibited. Smooth gathering of the material in the neck in which there are no sharp rooted folds shall be allowed;
- d) minimum wall thickness;
- e) water capacity;
- f) thread conformity.

**9.1.2** If finished cylinders are subjected to proof test, then 100 % of liners (if they are heat treated) shall be subjected to hardness testing after heat treatment in accordance with either ISO 6506-1 or ISO 6508-1 and shall achieve the limits specified in [7.2.2](#).

If finished cylinder is subjected to volumetric expansion pressure test, then 5 % of liners shall be subjected to hardness testing after heat treatment in accordance with either ISO 6506-1 or ISO 6508-1 and shall achieve the limits specified in [7.2.2](#).

**9.1.3** For heat treated liners, one liner from every batch of liners shall be tested to verify that the mechanical properties meet the minimum design requirements and according to the relevant standard for the liner material (see [Clause 2](#)). For cylinders above 10 l water capacity, a representative coupon for heat treatment can be substituted.

**9.1.4** For non-heat-treated liners, one liner from every batch of liners shall be tested in accordance with the liner burst test ([8.5.3](#)) to verify that the mechanical properties meet the minimum design requirements.

**9.1.5** A record of the tests carried out shall be kept by the cylinder manufacturer. Suitable forms of test certificate are shown in [Annex B](#).

**9.1.6** In the event of failure to meet test requirements, an investigation into the cause of failure and re-testing shall be carried out in accordance with [9.2](#).

## 9.2 Failure of liner batch tests

**9.2.1** If any of the test results are not satisfactory, and if the inspector is satisfied that this was due to an error in performing the test, a re-test shall be authorized using the same liner or if that is not possible, follow either a) or b).

- a) The test in question shall be repeated on a liner or test ring from the same batch, and if the results are satisfactory the batch shall be accepted.
- b) Where heat treatment has been shown to be inadequate, liners shall be subjected to re-treatment, and re-tested in accordance with [9.1.2](#) and [9.1.3](#). If the results are satisfactory the batch shall be accepted. This re-treatment can be conducted only once.

**9.2.2** Where heat treatment furnace records show artificial ageing has been inadequate, additional time at the ageing temperature shall be given.

**9.2.3** If the test results, having allowed for re-testing or re-heat treatment, are not satisfactory, liners in the batch shall be rendered unserviceable.

## 9.3 Overwrap materials

**9.3.1** Supplier's attestation of the material properties shall serve as verification of compliance. The strength of fibres shall be not less than specified in the documentation listed in [7.2.3](#).

**9.3.2** If attestation is not available, each batch of filament materials shall be subjected to an impregnated strand test in accordance with ISO 3341 for glass fibre, ASTM D7269 for aramid and ISO 10618 for carbon fibre, or equivalent. The strength of fibres shall be not less than specified in the documentation listed in [7.2.3](#).

## 9.4 Composite cylinder

**9.4.1** The inspector shall certify that the design, manufacture, inspection, and testing were carried out in accordance with this document. An example form of certificate is shown in [Annex B](#).

**9.4.2** Each batch of composite cylinders shall be examined and checked to ensure compliance with the design standard. The inspections that shall be carried out in accordance with the manufacturer's quality assurance procedures are:

- a) visual inspection of external and internal surface finish;
- b) dimensions;
- c) markings;
- d) water capacity;
- e) mass;
- f) cleanliness.

**9.4.3** The internal and external surfaces of the finished cylinder shall be free from defects and residues from the manufacturing process (e.g. swarf, resin) which would adversely affect the safe working of the cylinders.

NOTE See ISO 9809-1, ISO 9809-2, ISO 9809-3 and ISO 7866 for guidance on possible defects in metallic liners.

**9.4.4** Each completed cylinder shall be subjected to either a hydraulic proof test (in accordance with [8.5.1](#)) or a volumetric expansion test (in accordance with [8.5.2](#)) at the design test pressure specified in [7.2.4](#) as specified in the manufacturer's quality assurance procedures:

**9.4.5** A pressure cycling test shall be conducted on no less than one finished cylinder per five batches (a maximum of 1 000 pieces produced sequentially). The cylinder to be tested shall be selected at random from the five batches. If the cylinder fails the test, all five batches shall not be released until the investigation carried out in accordance with [9.5](#) is completed.

The cylinder shall be subjected to a hydraulic pressure cycle test to test pressure,  $p_h$ , for unspecified gas service or maximum developed pressure at 65 °C,  $p_{max}$ , for dedicated gas service. The procedure shall be in accordance with [8.5.5](#), except that the test can be suspended, as appropriate to the design, either after:

- 12 000 hydraulic cycles to test pressure;
- or 24 000 cycles to maximum developed pressure; or
- $N$  or  $N_d$  cycles as determined by [Formulae \(3\)](#) and [\(4\)](#):

$$N = t \times 250 \text{ cycle/year of design life} \quad (3)$$

$$N_d = t \times 500 \text{ cycle/year of design life} \quad (4)$$

where  $t$  is the number of years of design life.

Cylinders with test pressure of 60 bar and above shall withstand  $N$  pressurization cycles to test pressure,  $p_h$ , (up to a maximum of 12 000 cycles), or  $N_d$  pressurization cycles to maximum developed pressure,  $p_{max}$  (up to a maximum of 24 000 cycles), without failure by burst or leakage. Cylinders with test pressure below 60 bar shall withstand 12 000 pressurization cycles to test pressure,  $p_h$ , without failure by burst or leakage.

**9.4.6** One cylinder per batch of finished cylinders shall be subjected to a burst test in accordance with [8.5.4](#).

NOTE The cylinder subjected to the pressure cycle test (see [9.4.5](#)) can be used for this test.

The burst pressure,  $p_b$ , shall be in accordance with the criteria for the cylinder burst test specified in [8.5.4](#) for the relevant fibre.

## 9.5 Cylinder failure during type approval or batch testing

**9.5.1** In the event of failure to meet test requirements either during a production run (batch test) or when design type approval tests do not give satisfactory results, an investigation into the cause of failure and re-testing shall be carried out.

**9.5.2** If there is evidence of a fault in carrying out a test, or an error of measurement, a second test shall be performed on the same cylinder, if possible. If this is not possible then a second test shall be performed on a cylinder selected at random from the batch. If the results of this test are satisfactory, the first test shall be ignored.

**9.5.3** If the test has been carried out in a satisfactory manner, either:

- a) the cause of failure shall be identified, and the procedure detailed in [9.5.4](#) or [9.5.5](#) shall be followed; or

b) the batch shall be rejected and made unserviceable.

**9.5.4** If the cause of failure is identified, the defective cylinders can be reclaimed by an approved method or shall be rejected. All cylinders from the batch represented by the failed cylinder shall be tested and the passed and failed cylinders shall be separated into two batches. The failed test shall be repeated with the quantities required in 8.5.4 or 8.5.5 (as applicable) for both batches. For failures found during 100 % batch testing, only the repaired cylinders need to be re-tested. If one or more tests prove even partially unsatisfactory, all the cylinders of the batch(es) covered by the tests shall be rejected.

**9.5.5** Alternatively the cause of failure can be investigated and if this is identified the defective cylinders in the batch shall be removed from the batch and the failed test shall be repeated with the quantities required in 8.5.4 or 8.5.5 (as applicable) for the original batch.

**9.5.6** If a batch fails the second series of tests, the batch of cylinders shall be scrapped and rendered unserviceable for holding gas under pressure. The manufacturer shall ensure that the cylinders do not enter service.

## 10 Cylinder marking

### 10.1 General

Each finished composite cylinder which satisfies the requirement of this document shall be permanently and legibly marked in accordance with ISO 13769 and ISO 7225, or as relevant, except that the empty mass shall be the nominal mass.

NOTE Different requirements can exist in certain countries.

### 10.2 Additional marking

**10.2.1** When applicable, the cylinder shall be permanently and legibly marked using a label which is either attached to the cylinder surface, within the resin or under a glass fibre layer. The applicable information to be included on the label is dependent upon cylinder use, but shall be selected from:

- a) **“WARNING — FILL THIS CYLINDER ONLY WITH<< Named Gas(es) >>”** where a cylinder is to be used for dedicated gas service;
- b) **“WARNING — THIS CYLINDER MUST BE USED WITH A<< Named >>PRESSURE RELIEF DEVICE”** where a cylinder is approved with a specific pressure relief device (see 8.5.10);
- c) **“Maximum torque<< (manufacturer’s recommended torque) >>”** where fitting torque does not correspond to the values given in ISO 13341 or where the thread is not listed in ISO 13341;
- d) **“This tube has impact resistance level 1 (or 2)”**

As appropriate, for cylinders above 150 l where it is approved with a specific energy for the impact test (see 8.5.8).

- e) details of components that are permanently attached to the cylinder and form part of the qualified design (neck rings, protective boots, etc.) with instructions that they shall not be removed at periodic inspection;
- f) other additional markings such as re-test dates, customer names, etc.

**10.2.2** All labels shall be clearly marked with letters of height not less than 3 mm.

## Annex A

### (informative)

### Examples of design approval certificate

#### **Design approval certificate — Composite gas cylinders and tubes with non-load-sharing metallic or non-metallic liners**

Issued by (Relevant authority) on the basis of applying ISO 11119-2, *Gas cylinders — Design, construction and testing of refillable composite gas cylinders and tubes — Part 2: Fully wrapped fibre reinforced composite gas cylinders and tubes up to 450 L with load-sharing metal liners*

Approval No.	Date		
Cylinder description	(Family of cylinders which has received type approval)		
Manufacturer's drawing No.			
Design life	Underwater	Special torque	Pressure relief device
Liner heat treatment	Details		

Finished cylinder		Liner	Liner	Boss	Composite material
Capacity	l	Material			Fibre(s)
Test pressure	bar	Minimum thickness, mm			Fibre(s) tensile strength MPa
Diameter	mm	Minimum yield strength, MPa			Fibre(s) modulus GPa
Length	mm	Minimum tensile strength, MPa			Matrix components
Thread		Elongation, %			Shear strength MPa

Compatible gases	
Manufacturer or agent	(Name and address of manufacturer or his agent)
<hr/>	
Type of approval mark	
Details of the results of the examination of the design for design approval are detailed in Type Approval Test Report.	
All information can be obtained from	(Name and address of the approving body)
<hr/>	
Date	Place
Signature	

## Annex B

### (informative)

### Specimen test reports

**Verification bodies report on:**

**The manufacture of fully wrapped fibre reinforced composite gas cylinders and tubes with metal liners**

.....  
Inspection body .....

The inspector's mark .....

Certificate No. .....

Place ..... Date .....

Cylinders manufactured by .....

Manufacturer's mark .....

Manufactured for .....

Consigned to .....

Quantity ..... Overall size (mm) ..... Outside diameter by ..... long

Serial numbers ..... to ..... inclusive

**Standard**

Drawing No. .....

Date of hydraulic pressure test .....

Test pressure (bar) .....

Water capacity (l) .....

Gas ..... Filling pressure (permanent) (bar) .....

Filling ratio (liquefied) (bar) .....

Mass of container (kg) Minimum ..... Maximum ..... Without valve

Minimum ..... Maximum ..... With valve

NOTE Items in parentheses below refer to the clauses of this document.

Each liner was produced by over-wrapping a seamless liner with resin-impregnated filament reinforcement.

Liner material designated as ..... was supplied by ..... and the analysis was within the required limits.

Each liner was produced by an approved process. The results of the mechanical tests have been found satisfactory (see [9.1.3](#)).

Overwrap was applied by wrapping under controlled tension.

Glass

Carbon

Aramid

designated .....

supplied by .....

impregnated with resin designated .....

manufactured by .....

Identified by package number and cured after wrapping to the manufacturer's standard.

Filaments strand strength and reinforcement were verified and found satisfactory.

Calculated stress levels on the reinforcement filaments satisfy design requirements.

Each cylinder was subjected to a hydraulic proof pressure test (see [8.5.1](#)) or volumetric expansion test (see [8.5.2](#)) at the test pressure stated above.

The results of the batch pressure cycle and burst tests were satisfactory.

Each cylinder has been marked as required by ISO 11119-2, (Clause 10).

WE HEREBY CERTIFY that each of the above cylinders meets, in full, the requirements of ISO 11119-2.

For and on behalf of the manufacturer

.....

For and on behalf of the inspection body

.....