BS ISO 11119-4:2016

BSI Standards Publication

Gas cylinders — Refillable composite gas cylinders — Design, construction and testing

Part 4: Fully wrapped fibre reinforced composite gas cylinders up to 150 l with load-sharing welded metallic liners

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National foreword

This British Standard is the UK implementation of ISO 11119-4:2016.

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

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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INTERNATIONAL STANDARD

ISO 11119-4

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Gas cylinders — Refillable composite gas cylinders — Design, construction and testing —

Part 4: Fully wrapped fibre reinforced composite gas cylinders up to 150 l with load-sharing welded metallic liners

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

Partie 4: Bouteilles à gaz composites entièrement bobinées renforcées par des fibres et tubes d'une contenance allant jusqu'à 150 l avec liners métalliques transmettant la charge

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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).

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).

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

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 58, *Gas cylinders*, Subcommittee SC 3, *Cylinder design*.

ISO 11119 consists of the following parts, under the general title *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*

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

— *Part 3: Fully wrapped fibre reinforced composite gas cylinders and tubes up to 450L with non-load-sharing metallic or non-metallic liners*

— *Part 4: Fully wrapped fibre reinforced composite gas cylinders up to 150 l with load-sharing welded metallic liners*

Introduction

The purpose of this part of ISO 11119 is to provide a specification for the design, manufacture, inspection, and testing of a cylinder for worldwide usage. The objective is to balance design and economic efficiency against international acceptance and universal utility.

This part of ISO 11119 aims to eliminate the concern about climate, duplicate inspection, and restrictions currently existing because of a lack of definitive International Standards and is not to be construed as reflecting on the suitability of the practice of any nation or region.

It is possible that some procedures and tests will require precautions to be taken for the health and/or safety of the operator(s). Safety, health, and environmental concerns are not addressed and is to be addressed by those who wish to implement this International Standard.

This part of ISO 11119 is intended to be used under a variety of national and international regulatory regimes. Where there is any conflict between this part of ISO 11119 and any applicable regulation, the regulation always takes precedence.

This part of ISO 11119 has been written so that it is suitable to be referenced in the UN Model Regulations.[1]

Annexes A and B of this part of ISO 11119 are for information only.

Annex C of this part of ISO 11119 is normative.

INTERNATIONAL STANDARD **ISO 11119-4:2016(E)**

Gas cylinders — Refillable composite gas cylinders — Design, construction and testing —

Part 4: Fully wrapped fibre reinforced composite gas cylinders up to 150 l with load-sharing welded metallic liners

1 Scope

This part of ISO 11119 specifies requirements for composite gas cylinders with load-sharing welded liners between 0,5 l and 150 l water capacity and a maximum test pressure of 450 bar for the storage and conveyance of compressed or liquefied gases.

NOTE 1 1 bar = 10^5Pa = 10^5N/m^2.

The cylinders are constructed in the form of a welded stainless steel liner or welded ferritic steel liner or welded aluminium alloy liner and overwrapped with carbon fibre or aramid fibre or glass fibre (or a mixture thereof) in a matrix to provide longitudinal and circumferential reinforcement.

The cylinders in this part of ISO 11119 are type 3 fully wrapped cylinders with a load-sharing metal liner and composite reinforcement on both the cylindrical portion and the dome ends.

Cylinders produced in accordance with this part of ISO 11119 have a minimum design life of 15 years. Cylinders with test pressure of up to 60 bar have an unlimited design life.

This part of ISO 11119 does not address the design, fitting, and performance of removable protective sleeves.

This part of ISO 11119 does not apply to cylinders with seamless liners. For seamless liners, ISO 11119-2 applies.

NOTE 2 ISO 11623 covers periodic inspection and re-testing of composite cylinders.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. 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 4706:2008, *Gas cylinders — Refillable welded steel cylinders — Test pressure 60 bar and below*

ISO 5817:2014, *Welding — Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) — Quality levels for imperfections*

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 8521, *Plastics piping systems — Glass-reinforced thermosetting plastics (GRP) pipes — Test methods for the determination of the apparent initial circumferential tensile strength*

ISO 10042:2005, *Welding — Arc-welded joints in aluminium and its alloys — Quality levels for imperfections*

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

ISO 13769, *Gas cylinders — Stamp marking*

ISO 13919-1:1996, *Welding — Electron and laser-beam welded joints — Guidance on quality levels for imperfections — Part 1: Steel*

ISO 13919-2:2001, *Welding — Electron and laser beam welded joints — Guidance on quality levels for imperfections — Part 2: Aluminium and its weldable alloys*

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

ISO 18172-2:2007, *Gas cylinders — Refillable welded stainless steel cylinders — Part 2: Test pressure greater than 6 MPa*

ISO 20703:2006, *Gas cylinders — Refillable welded aluminium-alloy cylinders — Design, construction and testing*

ASTM D2290-12,*Standard test method for apparent hoop tensile strength of plastic or reinforced plastic pipe*

ASTM D2291-09, *Standard practice for fabrication of ring test specimens for glass-resin composites*

ASTM D2343-09, *Standard test method for tensile properties of glass fiber strands, yarns, and rovings used in reinforced plastics*

ASTM D2344/D2344M-13, *Standard test method for short-beam strength of polymer matrix composite materials and their laminates*

ASTM D4018-11, *Standard test methods for properties of continuous filament carbon and graphite fiber tows*

EN 14638-3:2010, *Transportable gas cylinders. Refillable welded receptacles of a capacity not exceeding 150 litres. Welded carbon steel cylinders made to a design justified by experimental methods*

3 Terms and definitions

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

3.1
fibre
continuous filaments laid up in tow form

3.2
autofrettage
pressure application procedure that 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 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 welding procedure, and design from the same material cast and heat treated (if applicable) at the same temperature and for the same period of time

3.4
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

3.5
burst pressure
highest pressure reached in a cylinder, p_b, or liner, p_{bl}, during a burst test

3.6
calculated liner proof pressure
pressure derived from the test pressure of the relevant liner design standard

Note 1 to entry: The liner design standards are given in Table 1. The calculated liner proof pressure is used for the liner integrity test.

3.7
composite overwrap
combination of fibres and matrix

3.8
dedicated gas service
service in which a cylinder is to be used only with a specified gas or group of gases

3.9
equivalent fibre
fibre 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 ±5 % of the fibre properties in an approved cylinder design

3.10
equivalent liner
liner that is manufactured from the same nominal raw materials, using the same process(es) of manufacture and having the same physical structure and the same nominal physical properties as in an approved cylinder design

3.11
exterior coating
layers of material applied to the cylinder as protection or for cosmetic purposes

Note 1 to entry: The coating can be clear or pigmented.

3.12
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

3.13
load-sharing liner
liner that has a burst pressure greater than or equal to 5 % of the nominal burst pressure of the finished composite cylinder

3.14
thermoplastic material
plastics capable of being repeatedly softened by increase of temperature and hardened by decrease of temperature

3.15
thermosetting material
plastics that hardens permanently into a substantially infusible and insoluble product when cured by the application of heat or chemical means

3.16
working pressure
settled pressure of a compressed gas at a reference temperature of 15 °C in a full gas cylinder

3.17
nominal outside diameter
diameter of the cylinder specified by the manufacturer for the type approval including tolerances

EXAMPLE Tolerances could be ±1 %.

3.18
type 3 cylinder
fully wrapped cylinder with a load-sharing metal liner and composite reinforcement on both cylindrical and dome ends

3.19
test pressure
$\boldsymbol{p_h}$
required pressure applied during the pressure test of the composite cylinder

4 Symbols

Symbols and their designations

Symbol	Designation	Unit
p_b	burst pressure of finished cylinder	bar
p_h	test pressure	bar
p_{max}	maximum developed pressure at 65 °C	bar
p_w	working pressure	bar
P_{bl}	burst pressure of the liner	bar
P_l	calculated liner proof pressure for liner integrity test	bar
N	number of cycles with pressurization to test pressure	units
N_d	number of cycles with a pressurization to maximum developed pressure	units
Y	number of years of design life	units
B	width of weld reinforcement	mm
h	height or width of imperfection	mm
t	wall or plate thickness (nominal size)	mm

5 Inspection and testing

Evaluation of conformity shall be carried out in accordance with the applicable regulations of the countries of use.

To ensure that the cylinders conform to this part of ISO 11119, 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.

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 requirements are given in Table 1.

Table 1 — Liner requirements

Type of liner	Liner material	Liner heat treatment	Applicable standard	Relevant sections of the applicable standard
Welded steel liner	Carbon steel	Yes	ISO 4706:2008	5, 6.3, 8, 9
		No	EN 14638-3:2010	4, 5.4, 6, 8
	Stainless steel	As defined in the standard	ISO 18172-2:2007	4, 5.6, 6, 8
Welded aluminium Alloy liner	Aluminium alloy	As defined in the standard	ISO 20703:2006	4, 5.4, 6, 7

Design requirements are excluded as these are specified by the manufacturer for the design of the composite cylinder (7.2.4).

6.1.2 The composite cylinder manufacturer shall verify that each new batch of materials has the correct properties and is of satisfactory quality and records shall be maintained 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.

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 filament material and the matrix system component materials shall be accompanied with sufficient documentation to be able to fully identify the batch of materials used in the manufacture of each cylinder.

6.2.4 The composite cylinder manufacturer shall verify that each new batch of materials has the correct properties and is of satisfactory quality, and shall 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 welded liner shall comprise of the following:

a) an internal metal liner which carries part of the longitudinal and circumferential load. For cylinders with test pressure above 60 bar, the maximum permissible load share by the liner shall be 30 %, which results in a maximum liner burst pressure of 30 % of minimum burst pressure of the finished cylinder;

b) a composite overwrap formed by layers of continuous fibres in a matrix;

c) an optional external protection system.

There shall be no adverse reaction or interaction (e.g. epoxy coating with epoxy matrix) between the liner and the reinforcing fibre by the application of a suitable protective coating to the liner prior to the wrapping process.

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. Construction and workmanship requirements shall be in accordance with those in the standards listed in Table 1. If the cylinder includes permanently attached components (e.g. neck rings), they shall be considered as an integral part of the cylinder and form part of the qualified design.

NOTE Examples of certificates are shown in Annexes A and B.

7.1.2 Cylinders with a test pressure less than 60 bar shall have a non-limited design life

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 specified 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) the following:

a) the material, including limits of chemical analysis;

b) the dimensions, minimum wall thickness, straightness, and out-of-roundness with tolerances;

c) the process and specification of manufacture;

d) the weld profile including the manufacturing procedure, dimensions and tolerances, and the maximum limits for excess weld metal as specified in 7.3.1 a);

e) the heat treatment, temperatures, duration, and tolerances, if applicable;

f) the inspection procedures (in addition to those specified on the referred liner standard in accordance with Table 1);

g) the material properties including minimum mechanical properties and hardness ranges, where applicable;

h) the calculated proof pressure of the liner for liner integrity test, P_l (in accordance with 8.5.4);

i) the minimum design burst pressure, P_{bl};

j) the 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) the following:

a) the fibre material, specification, and mechanical properties requirements (the mechanical properties shall be as specified by the manufacturer);

b) the minimum composite thickness;

c) the thermosetting matrix – specifications (including resin, curing agent, and accelerator) and resin bath temperature where applicable;

d) the thermoplastic matrix system – main component materials, specifications, and process temperatures;

e) the overwrap construction including the number of strands used, number of layers, and layer orientation and tensioning of the fibre at wrapping; this tension can be either a process tension to aid the wrapping process or the much higher pre-tensioning to actively change the final stresses in the finished cylinder;

f) the curing process, temperatures, duration, and tolerances, where applicable.

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

a) the nominal water capacity in litres at ambient conditions;

b) the dimensions with tolerances;

c) the list of intended contents if intended for dedicated gas service;

d) the test pressure, P_h;

e) the working pressure, P_w (if applicable), that shall not exceed 2/3 × P_h test pressure;

f) the maximum developed pressure at 65 °C for specific dedicated gas(es), P_{max};

g) the minimum design burst pressure, P_b;

h) the design life in years;

i) the autofrettage pressure and approximate duration or details of the fibre tensioning, if applicable;

j) the nominal mass of the finished composite cylinder, including tolerances;

k) the details of components which are permanently attached and form part of the qualified design (e.g. neck rings, protective boots);

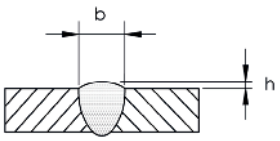
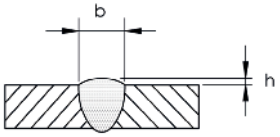
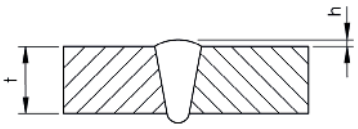
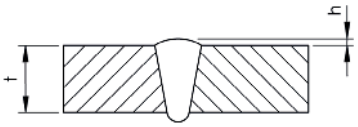
l) the additional test requirements for special applications.

7.3 Manufacturing

7.3.1 The liner shall be manufactured in accordance with the manufacturer's design (see 7.2.2) and standard for the relevant liner requirements (as specified in 6.1.1).

a) The weld profile shall not exceed the dimensions and tolerances and the maximum limits for excess weld metal as specified in Table 2.

Table 2 — Excess weld metal limits

Standard	Figure	Limits for imperfections for quality level
ISO 5817:2014, Table 1 No. 1.9, for fusion welded joint in steel, nickel, titanium and their alloys		$h \leq 1$ mm + 0,1 b, but max. 5 mm
ISO 10042:2005, Table 1 No. 1.11, for arc welded joints in aluminium and their alloys		$h \leq 1{,}5$ mm + 0,1 b, but max. 6 mm
ISO 13919-1:1996, Table 2 No. 11, for electron and laser beam joints in steel		$h \leq 0{,}2$ mm + 0,15 t, or 5 mm, whichever is the smaller
ISO 13919-2:2001, Table 2 No. 12, for electron and laser beam joints in aluminum and its weldable alloys		$h \leq 0{,}2$ mm + 0,15 t, max. 5 mm

b) Welded joints shall conform to ISO 5817 quality level B (for steel, nickel, and titanium and their alloys) or ISO 10042 (for aluminium and its alloys) quality level B or ISO 13919-1 (for steel) quality level C or ISO 13919-2 quality level C (for aluminium and its alloys).

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 may 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 applicable) using a controlled temperature profile as specified in 7.2.3. The cure process 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). The liners for cylinders subject to autofrettage shall be heat treated.

7.3.5 If cylinders are subjected to a pre-stressing or fibre tensioning during wrapping in order to actively change the final stresses in the finished cylinder, the tension shall be as specified in the documentation referred to in 7.2.3 and 7.2.4 and shall be monitored and recorded.

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 on each new cylinder design or design variant.

Annex C specifies the prototype tests to be conducted and specifies the test frequency.

8.2 Prototype tests

8.2.1 A minimum of 30 cylinders that are representative of the new design in their finish form shall be made available for prototype testing. Upon successful completion of all prototype tests, the remaining untested cylinders from the prototype qualification batch may be used for service.

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

For a limited design change (design variant), in accordance with Table 3, a reduced number of cylinders shall be selected.

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 9.2.

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 9.4.

8.2.5 Verify that the material and design meet the requirements of Clauses 6 and 7 and the cylinders necessary for destructive testing shall be randomly selected. A dimensional check for conformity to the drawing and the parameters as specified in the design submission (see 7.2) shall be performed on all liners and cylinders selected for destructive testing.

The tests shall consist of the following:

a) the hydraulic or pneumatic proof pressure test, in accordance with 8.5.1, or hydraulic volumetric expansion test, in accordance with 8.5.2;

b) the liner burst tests, in accordance with 8.5.3;

c) the liner integrity test, in accordance with 8.5.4;

d) the cylinder burst test, in accordance with 8.5.5;

e) the ambient temperature cycle test, in accordance with 8.5.6;

f) the environmental cycle test, in accordance with 8.5.7;

g) the flaw test, in accordance with 8.5.8;

h) the drop test, in accordance with 8.5.9;

i) the high velocity impact (gunfire) test, in accordance with 8.5.10;

j) the torque test, in accordance with 8.5.13;

k) the leak test, in accordance with 8.5.15;

l) the composite materials mechanical properties tests, in accordance with 8.5.16.

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

a) the fire resistance test, in accordance with 8.5.11;

b) the salt water immersion test, in accordance with 8.5.12;

c) the environmentally assisted stress rupture test, in accordance with 8.5.14.

8.2.7 For approval of a design variant as specified in 8.4, it is only necessary to perform the tests as specified in Table 3 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 may be used as applicable (see 8.4.2).

8.2.8 Tests may be combined such that one cylinder can be used for more than one test. For example, the cylinder used in drop test (see 8.5.9) may be used to perform the burst test specified in 8.5.5.

8.2.9 If the results of the prototype tests are satisfactory, the inspector shall issue a type approval certificate.

NOTE A typical example of a type approval certificate is given in Annex A.

8.2.10 After completion of the tests, the cylinders shall be destroyed or rendered unserviceable.

8.3 New design

8.3.1 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 the method of manufacture or cylinder design has changed to a significant extent, for example:

a) The cylinder 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. These conditions shall be verified by the inspector.

b) The cylinder 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. The cylinder is manufactured with a new fibre type. A fibre of the same specification classification and mechanical properties but with a different linear density (mass per unit length) shall not be considered a new fibre type. A fibre shall be considered to be of a new fibre type when:

   1) the fibre is of a different type (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.

d) The matrix materials (i.e. resin, curing agent, and accelerator) are different and not chemically equivalent to the original design (e.g. a change from an epoxy to a polyester).

e) The test pressure has increased by more than 60 % from the qualified design.

8.3.2 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, for example:

a) The liner 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. These conditions shall be verified by the inspector.

b) The liner is manufactured from a material of different composition or composition limits from that used in the original type tests.

c) The material properties are outside the original design limits.

d) Different welding technology is used, e.g. weld configuration.

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 3. 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) the pre-stressing parameters have changed by more than 5 %;

e) there is a change in the design test pressure up to and including 60 %; 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;

f) 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;

g) the minimum wall thickness of the liner has changed by more than 5 %;

h) there have been changes to the composite thickness or wrap pattern other than the changes necessary to accommodate the changes of diameter and/or length;

i) the matrix materials (i.e. resin, curing agent, and accelerator) are chemically equivalent to the original design;

j) when equivalent overwrapping fibres are used;

1) 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 ±5 % of the fibre properties in an approved cylinder design.

NOTE Carbon fibres made from the same precursor can be equivalent. Aramid, carbon, and glass fibres are not equivalent.

2) Where a new equivalent fibre has been successfully 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.

k) when an equivalent liner is used;

1) Equivalent liners shall be manufactured by the same welding procedure resulting in the same weld configuration (same materials and parameters).

2) The equivalent liner material shall be subjected to the material tests specified in 9.2.3 and the liner burst test specified in 8.5.3 and in both cases shall meet the requirements specified in 7.2.2.

3) Where a new equivalent liner has been successfully 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.

l) when the cylinder inlet thread has changed.

When a cylinder design has only a different thread compared with an approved design, only the torque test, in accordance with 8.5.13, 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.

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 3, 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).

Table 3 — Type approval tests

Test no.	Test	New design	Design variant changes											
			Nominal length		Nominal diameter		Equivalent liner	Liner thickness change	Test pressure		Composite thick or liner base form	Equivalent fibre	Equivalent matrix	Autofrettage or pre-tension
			>5 % ≤ 50 %	>50 %	≤20 %	>20 % ≤ 50 %			≤20 %[c]	>20 % ≤ 60 %				
9.2	Liner material test	X					X	X						
9.4	Composite material tests	X										X	X	
8.5.1/8.5.2	Hydraulic pressure	X	X	X	X	X	X	X	X	X	X	X		X
8.5.3	Liner burst	X		X	X	X	X	X		X				
8.5.4	Liner integrity test	X		X	X	X	X	X		X				
8.5.5	Hydraulic burst	X	X	X	X	X	X	X	X	X	X	X	X	X
8.5.6	Ambient cycle	X	X	X	X	X	X	X	X	X	X	X	X	X
8.5.7	Environmental cycle	X											X	
8.5.8	Flaw	X				X								
8.5.9	Drop	X		X		X		X[b]		X		X		
8.5.10	High velocity impact	X				X[c]		X[b]		X				
8.5.11	Fire resistance[a]	X		X		X		X[b]		X				
8.5.12	Salt water[a]	X											X	
8.5.13	Torque test[f]	X												
8.5.14	Stress rupture test[a]	X				X[d]				X[d]	X[d]			X[e]
8.5.15	Leak test	X				X				X	X	X	X	X
8.5.16	Composite material mechanical properties tests	X										X	X	

[a] Optional test required depending on the design and intended use of the cylinder.

[b] This test shall be performed with a liner thickness decrease only.

[c] This test shall be performed for reduction in diameter only.

[d] This test shall be performed where burst pressure to test pressure ratio of design variant is over 20 % greater than the same ratio for the approved design.

[e] This test shall be performed for an increase in autofrettage pressure of greater than 15 %.

[f] When a cylinder design has only a different thread compared with an approved design, only the torque test, in accordance with 8.5.13, shall be performed.

8.5 Type approval test procedures and criteria

8.5.1 Proof pressure test

8.5.1.1 Procedure

When performing the pressure test, a suitable fluid (e.g. 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. The cylinder test pressure shall be held for at least 30 s with the cylinder isolated from the pressure source, during which 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.

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

The limit deviation on attaining test pressure shall be (P_h +3/−0 %) or (P_h +10/−0 bar), whichever is the lower. Pressure gauges with the appropriate accuracy and scale increments shall be used.

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

Alternatively, a pneumatic pressure test may 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 test, a suitable fluid (e.g. 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. The cylinder test pressure shall be held for at least 30 s with the cylinder isolated from the pressure source, during which 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/−0 %) or (P_h +10/−0 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 either

a) there are leaks or failure to hold pressure, or

b) it shows a 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 per second. The test shall be performed under ambient conditions.

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

a) the burst pressure;

b) the number of pieces;

c) the description of failure;

d) the pressure/time curve or pressure/volume curve.

8.5.3.2 Criteria

The liner burst pressure, P_{bl}, shall be not less than the minimum design burst pressure specified in the design submission (see 7.2.2). For cylinders with a test pressure above 60 bar, the liner burst pressure shall not exceed 30 % of the finished cylinder minimum burst pressure. Failure shall not initiate at the welds and the liner shall remain in one piece.

8.5.4 Liner integrity test

8.5.4.1 General

The liner shall be pneumatically tested prior to winding to a calculated proof pressure.

The calculated liner proof pressure shall be specified by the manufacturer as part of the design submission (see 7.2.2).

The parameters that shall be checked are

a) the leak tightness at calculated liner proof pressure, and

b) the ability of the liner to withstand the calculated liner proof pressure without permanent deformation.

8.5.4.2 Procedure

The pressure in the liner shall be increased gradually and regularly until the calculated liner proof pressure is reached. The pressure shall be held long enough to determine leak tightness.

WARNING — Appropriate measures shall be taken to ensure safe operation and to contain any energy that may be released. It should be noted that pneumatic pressure tests require more precautions than hydraulic pressure tests as, regardless of the size of the container, any error in carrying out this test is highly likely to lead to a rupture under gas pressure. Therefore, these tests shall be carried out only after ensuring that the safety measures satisfy the safety requirements.

The pressurized liner shall be immersed in water to allow the observation of leakages. Alternative methods resulting in the same accuracy may be used.

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

The calculated liner proof pressure shall be monitored.

8.5.4.3 Criteria

a) No permanent deformation shall be visible during and after the test.

b) No visible leakage shall occur.

8.5.5 Cylinder burst test

8.5.5.1 Procedure

Three cylinders shall be tested hydraulically to destruction by pressurizing at a rate of no more than 10 bar. The test shall be performed 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 the following:

a) the burst pressure;

b) the description of failure;

c) the pressure/time curve or pressure/volume curve.

8.5.5.2 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 the test pressure, $P_h \times 2{,}0$.

c) The burst pressure, P_b, for cylinders with aramid fibre reinforcement shall be not less than the test pressure $P_h \times 2{,}1$.

d) The burst pressure, P_b, for cylinders with glass fibre reinforcement shall be not less than the test pressure, $P_h \times 2{,}4$.

In any case, the failure shall not initiate at the welds.

8.5.6 Ambient cycle test

Cylinders with the maximum specified limit for excess weld metal shall be used for ambient cycle test during prototype testing. Perform leak test, in accordance with 8.5.15, immediately after finishing the minimum required cycles.

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

8.5.6.1.1 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).

8.5.6.1.2 Procedure

Two cylinders shall be subjected to a hydraulic pressure cycle test to test pressure, P_h, for unspecified gas service or maximum developed pressure, P_{max}, at 65 °C, 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, P_{max}, at 65 °C, 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 the following:

a) the maximum excess of weld material (to be measured on the liner prior to wrapping);

b) the temperature of the cylinder;

c) the number of cycles achieving upper cyclic pressure;

d) the minimum and maximum cyclic pressures;

e) the cycle frequency;

f) the test medium used;

g) the mode of failure, if appropriate.

8.5.6.1.3 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, where:

$$N = y \times 250 \text{ cycles per year of design life;}$$

$$N_d = y \times 500 \text{ cycles per year of design life;}$$

$$y = \text{the number of years of design life.}$$

y shall be a whole number which is not less than 15 years.

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 4).

Table 4 — Criteria for the ambient cycle test

	1st part	2nd part
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 1st part	Burst = Fail

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 consistently in the test, it is not necessary to limit the design life of the cylinder.

For cylinders used for prototype testing, a leak test in accordance with 8.5.15 shall be performed immediately after accomplishing the minimum design required cycles.

8.5.6.2 For cylinders with test pressure less than 60 bar

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

a) the maximum excess of weld material (to be measured on the liner prior to wrapping);

b) the temperature of the cylinder;

c) the number of cycles achieving upper cyclic pressure;

d) the minimum and maximum cyclic pressures;

e) the cycle frequency;

f) the test medium used;

g) the mode of failure, if appropriate.

8.5.6.2.2 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.

8.5.7 Environmental cycle test

8.5.7.1 General

The tests in this section will be performed in an environmental chamber. One cylinder, without paint or removable protective coating and/or casing, shall be tested.

8.5.7.2 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 shall not degrade from those at ambient temperature when used at the test temperature extremes.

Condition the 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 %. 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 is capable of meeting the cylinder pressure cycling requirements.

Seal the cylinder in the environmental test chamber and perform the following sequence of tests:

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 2/3 P_h and less than 10 % of working pressure (6,67 % of test pressure) for 5 000 cycles using the external pressurizing medium supplied at ambient temperature.

The cycling frequency shall not exceed five cycles per minute.

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

Once the required number of 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 2/3 P_h for 5 000 cycles using the external pressurizing medium supplied at ambient temperature.

The cycling frequency shall not exceed five cycles per minute.

During the test, the cylinder surface temperature shall be maintained 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 the requirements in 8.5.5.

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

— the cylinder surface temperature throughout the test;

— the test chamber humidity;

— the cylinder pressurization medium used;

— the number of pressure cycles completed (a complete cycle will have achieved the required test pressure);

— the minimum and maximum cyclic pressures achieved for each test cycle;

— the pressure cycle frequency;

— the parameters specified in 8.5.5.

8.5.7.3 Criteria

a) The burst pressure shall be greater than 85 % of the minimum design burst pressure.

b) The burst pressure, P_b, for cylinders with carbon fibre reinforcement shall be not less than the test pressure, $P_h \times 1{,}7$.

c) The burst pressure, P_b, for cylinders with aramid fibre reinforcement shall be not less than the test pressure, $P_h \times 1{,}9$.

d) The burst pressure, P_b, for cylinders with glass fibre reinforcement shall be not less than the test pressure, $P_h \times 2{,}2$.

8.5.8 Flaw test

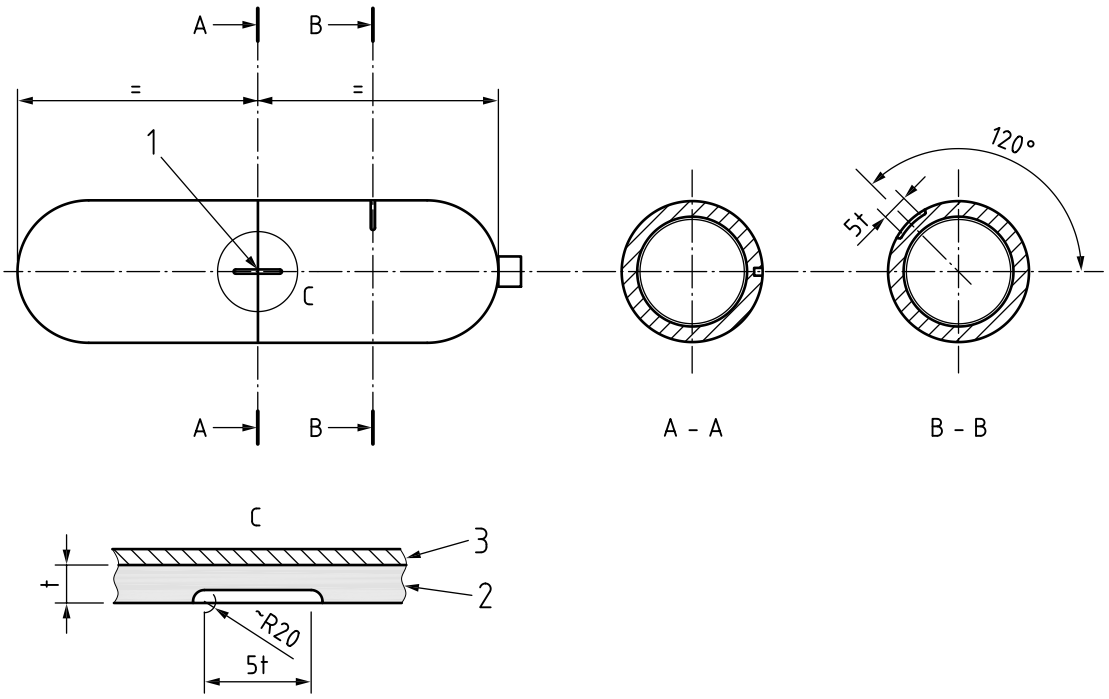
8.5.8.1 Procedure

Two cylinders shall be tested.

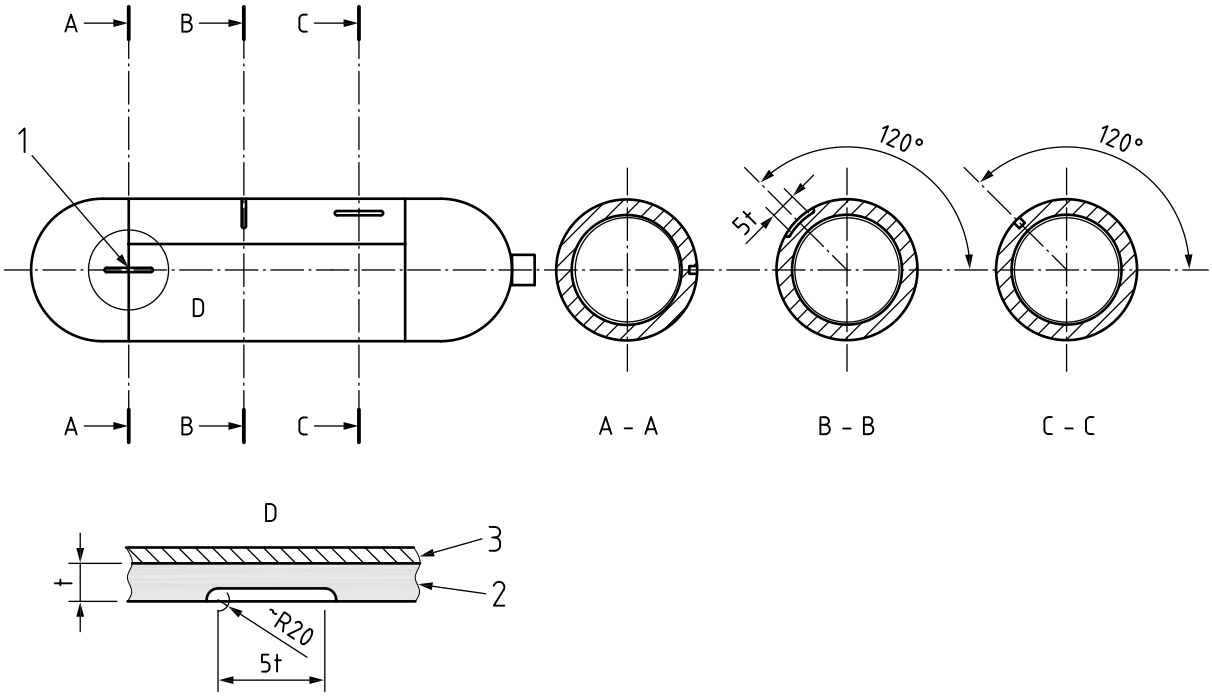
Depending on the liner construction (two-part welded or three-part welded), one or two longitudinal flaws shall be cut into each cylinder in the mid-length of the cylindrical wall of the cylinder in accordance with Figure 1 a), b), or c). The flaw shall be made with a 1 mm thick cutter to a depth equal to at least 50 % of the composite thickness 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.

Another transverse flaw of the same dimensions shall be cut into each cylinder as shown in Figure 1 a), b), or c), in the mid-length of the cylindrical wall approximately 120° around the circumference from the other flaw in accordance with Figure 1.

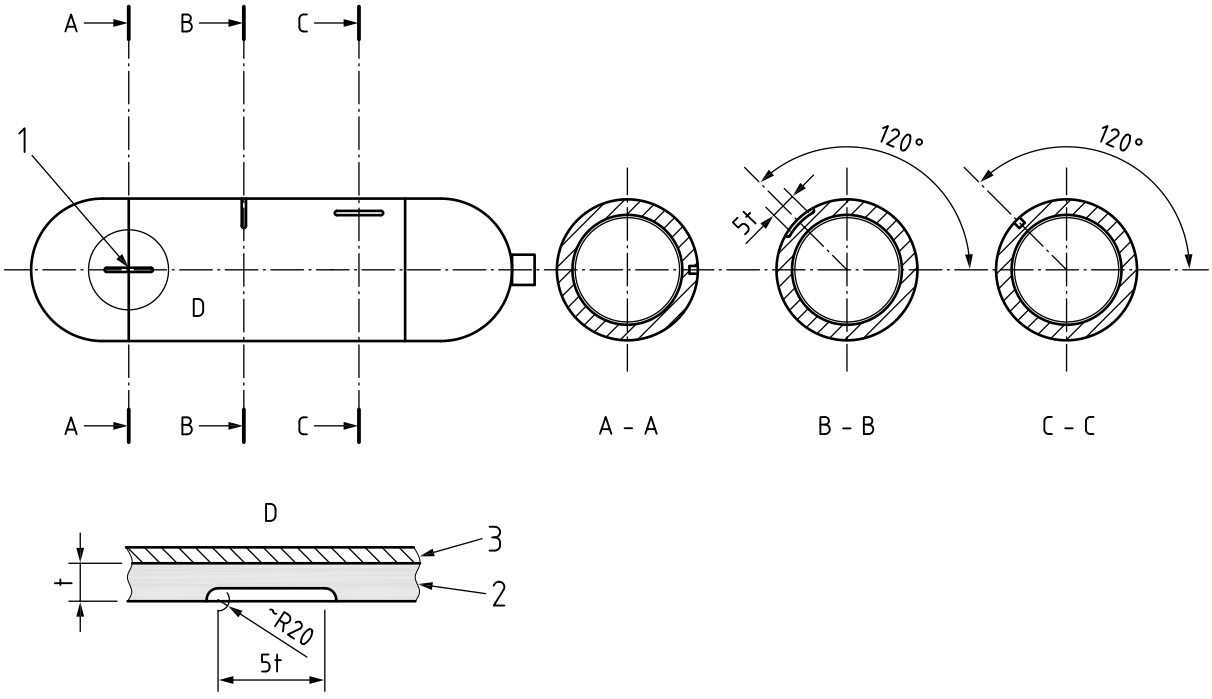
One cylinder shall be subjected to the burst test specified in 8.5.5.



a) With two-part welded liner



b) With three-part welded liner (with two circumferential and one longitudinal weld)



c) With three-part welded liner (with two circumferential welds)

Key

1 1 mm wide
2 wrap
3 liner
t composite thickness

Figure 1 — Flaw test cylinder

The other cylinder shall be subjected to the pressure cycling test in 8.5.6, but the upper cyclic pressure shall be the test pressure, $P_h \times 2/3$, 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 the following:

a) the dimensions of flaws;

b) the temperature of the cylinder;

c) the number of cycles achieving upper cyclic pressure;

d) the minimum and maximum cyclic pressures;

e) the cycle frequency;

f) the test medium used;

g) the mode of failure, if appropriate.

8.5.8.2 Criteria

First cylinder: Burst pressure, P_b, shall be equal to or greater than the test pressure $P_h \times 4/3$.

Second cylinder: The cylinder shall withstand at least 1 000 pressure cycles to the test pressure $P_h \times 2/3$ 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.

8.5.9 Drop test

8.5.9.1 For cylinders up to and including 50 l water capacity

8.5.9.1.1 Procedure

Two cylinders shall be filled with water to 50 % capacity and fitted with a plug flush with the end of each cylinder.

Both cylinder shall be dropped twice, in each of the five positions shown in Figure 2, from a minimum height of 1,2 m on to a steel plate of a minimum of 5 mm thickness. The protective plate 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 in 8.5.5.

The other cylinder shall be subjected to the pressure cycling test in 8.5.6.

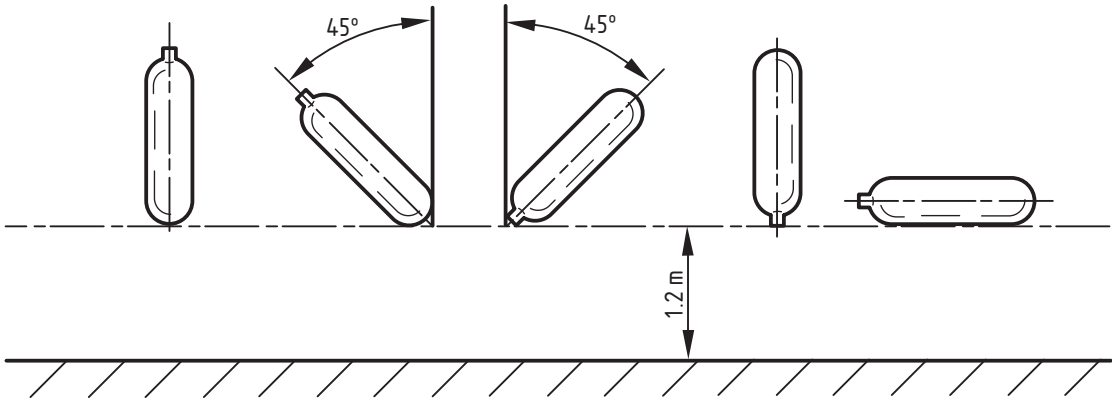


Figure 2 — Drop test

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

a) the visual appearance after each drop — record position and dimensions of impact damage;

b) the parameters specified in test 8.5.5 (cylinder burst test);

c) the parameters specified in test 8.5.6 (cylinder cycle test).

8.5.9.1.2 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 in 8.5.5 for the relevant fibre.

Second cylinder: The cylinder shall satisfy the requirements of the ambient cycle test in 8.5.6.

8.5.9.2 For cylinders over 50 l water capacity

8.5.9.2.1 Procedure

a) One or more empty cylinders, fitted 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 smooth, horizontal, and concrete pad or flooring.

b) 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 joules, but in no case shall the height of the lower end 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 closer to the ground than 0,6 m, the drop angle should be changed to maintain a minimum height of 0,6 m and a centre of gravity of 1,8 m. The cylinder 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 may be prevented from toppling during the vertical drop test.

8.5.9.2.2 Criteria

The cylinders shall withstand 3 000 pressurization cycles at the test pressure $P_h \times 2/3$ 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.

8.5.10 High velocity impact (gunfire) test

8.5.10.1 Procedure

One cylinder shall be filled to the working pressure ($P_h \times 2/3$) 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 is positioned in such a way that the point of impact of the projectile is in the cylinder side wall at a nominal angle of 45° and such that the bullet would also exit through the cylinder side wall.

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 of not more than 45 m. The cylinder shall be safely vented before removing from the test.

Cylinders with diameter of 120 mm and below shall be impacted by a 5,6 mm (or 0,22 calibre) armour piercing bullet with a nominal speed of 850 m/s. The bullet shall be fired from a distance of not more than 45 m. The cylinder shall be safely vented before removing from the test.

The dimensions of the entrance and exit openings are measured and recorded.

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

a) the type of projectile;

b) the initial pressure;

c) the description of failure;

d) the approximate size of the entrance and exit openings.

8.5.10.2 Criteria

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

8.5.11 Fire resistance test

8.5.11.1 General

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.

8.5.11.2 Procedure

Two cylinders shall be fitted with either

a) the valves and PRDs intended for use, if known, or

b) a valve fitted with bursting disc set to operate at between P_h and 1,15 P_h.

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 filled with air or nitrogen or the compressed gas intended for use to the working pressure (P_h × 2/3). The cylinder intended to be used with liquefied gas shall be filled with the corresponding filling ratio.

NOTE Special care has to be taken when testing cylinders with flammable liquefied gases.

A uniform fire source of 165 m length shall be used that is capable of enveloping the entire diameter of the cylinder, when in the horizontal position, and producing a temperature ≥590 °C, measured 25 mm below the cylinder within 2 min.

Any fuel may 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.

The cylinders shall be tested in both the vertical and the horizontal position.

Vertical: 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 wood, in the case of a wood fire, or 0,1 m from the surface of the liquid in a fuel-based fire. The relief device shall be shielded from direct flame impingement.

Horizontal: 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 wood, in the case of a wood fire, or 0,1 m from the surface of the liquid in a fuel-based fire. The relief device is to be shielded from direct flame impingement.

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 the following:

a) the type and characteristics of pressure relief device;

b) the initial pressure;

c) the location of leak;

d) the temperature;

e) the time.

8.5.11.3 Criteria

The cylinder shall not burst during a period of 2 min from the start of the fire test. It can vent through the pressure relief device or leak through the cylinder wall or other surfaces.

8.5.12 Salt water immersion test

8.5.12.1 General

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

8.5.12.2 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 the test pressure $P_h \times 2/3$ for not less than 22 h.

(b) Drying period

The pressurized cylinders shall then be taken out from salt water immersion 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 the test pressure $P_h \times 2/3$ 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 8.5.5. The other cylinder shall be submitted to pressure cycling in accordance with 8.5.6.

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

a) the temperature of the solution, at least once a day;

b) the filling pressure;

c) the duration of immersion;

d) the quantity of salt added to a given volume;

e) the parameters specified in test 8.5.5;

f) the parameters specified in test 8.5.6.

8.5.12.3 Criteria

The burst pressure, P_b, shall be not less than the burst pressure in 8.5.5 for the relevant fibre.

The second cylinder shall satisfy the criteria for the ambient cycle test (see 8.5.6).

8.5.13 Torque test

8.5.13.1 Procedure

The body of the cylinder shall be held in a manner to prevent it from rotating. The cylinder shall be fitted with a corresponding valve and tightened to 150 % of the maximum torque recommended in ISO 13341 for the relevant liner material, or as recommended by the manufacturer where this part of ISO 11119 does not apply.

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

a) the type of valve/plug material;

b) the valving procedure;

c) the applied torque.

8.5.13.2 Criteria

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

8.5.14 Environmentally assisted stress rupture test

8.5.14.1 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 ± 5) °C and a relative humidity equal to or greater than 95 %. Use of a water spray or suspending the cylinder over water bath will meet the requirements of this test.

After this test, the cylinders shall be subjected to the burst test (see 8.5.5).

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

a) the temperature and relative humidity, at least twice a day;

b) the cylinder pressure, at least twice a day;

c) the burst pressure.

8.5.14.2 Criteria

The cylinder shall not exhibit any visible deformation or loose fibres (unravelling) and the burst pressure shall be equal to or greater than 100 % of the minimum burst level required in the burst test (8.5.5) for the relevant fibre.

8.5.15 Leak test

8.5.15.1 Procedure

Leak testing shall be performed at a minimum of 2/3 times test pressure, P_h.

Acceptable methods for leak testing include, but are not limited to, bubble testing using dry air or gas or measurement of trace gases using a mass spectrometer.

Special care should be taken to assure the cylinder is dry before performing this test.

8.5.15.2 Criteria

Leakage greater than 6 cm^3/h, which is approximately four bubbles of 3,5 mm in diameter per minute, constitute a failure of the test.

8.5.16 Composite material mechanical properties tests

8.5.16.1 Procedure

Tests on the composite materials to establish their mechanical properties shall be performed in accordance with the following:

a) fibre tensile properties;

   1) for glass, aramid: ISO 8521 or ASTM D2290-12 and ASTM D2291-09;

      ISO 3341 or ASTM D2343-09;

   2) for carbon ISO 10618 or ASTM D4018-11;

b) shear properties: ISO 14130 or ASTM D2344/D2344M-13.

Equivalent tests in accordance with alternative standards or test specifications acceptable to the inspector may be applied.

8.5.16.2 Criteria

The mechanical properties shall meet the minimum requirements for the design as specified in 7.2.3 in the design submission.

8.5.17 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 performed in accordance with 9.6.

9 Batch inspection and testing

9.1 General

In the course of batch testing, all tests for checking the quality of the cylinders shall be performed at the completion of the cylinder manufacturing. The manufacturer shall provide the inspector with the following:

a) a type approval certificate;

b) certificates for the raw material;

c) certificates for NDT (non-destructive test);

d) a list of the cylinders, stating serial numbers and stamp markings as required;

e) a confirmation that threads have been checked in accordance with the gauging requirement.

During batch testing, the inspector shall perform the following:

a) ascertain that the type approval certificates has been obtained and that the cylinders conform to it;

b) verify that the requirements given in Clauses 6, 7, and 8 have been met and in particular, checked by an external and internal visual examination of the cylinders to ensure that their construction is satisfactory. The inspector shall verify that the documentation conforms to the requirements of 7.2.2, 7.2.3, and 7.2.4;

c) select the necessary liners and cylinders per batch for destructive testing and perform the tests.

Annex C gives an overview of all the necessary tests to be performed under the supervision of the inspector and specifies the test frequency.

9.2 Liner

9.2.1 Each batch of liners shall be examined and dimensionally checked to ensure conformity to the design specification. The following checks shall be performed but are not limited to the following:

a) the visual inspection of external and internal surface finish including the welds;

b) the dimensions;

c) the minimum wall thickness;

d) the water capacity;

e) the welded joints shall conform to ISO 5817 quality level B or ISO 10042 quality level B or ISO 13919-1 quality level C or ISO 13919-2 quality level C;

f) the weld profile shall not exceed the dimensions and tolerances and the maximum limits for excess weld metal as documented in 7.2.2 d);

g) for cylinders with test pressure above 60 bar, each liner weld shall be examined to ensure its integrity by using a radioscopy-based process or an equivalent NDT test method;

h) each completed liner shall be subjected to the liner integrity test, in accordance with 8.5.4;

i) thread conformity.

9.2.2 One liner from each liner batch shall be tested to verify that the mechanical properties meet the minimum design requirements.

9.2.3 If finished cylinders with test pressure above 60 bar are subjected to a proof pressure test (see 8.5.1), then each of the liners (if they are heat treated) shall be subjected to a hardness test after heat treatment in accordance with either ISO 6506-1 or ISO 6508-1 or other equivalent method (e.g. conductivity) and shall achieve the limits specified in 7.2.2.

If finished cylinders with test pressure above 60 bar are subjected to volumetric expansion test (see 8.5.2), then 5 % of liners shall be subjected to a hardness test after heat treatment in accordance with either ISO 6506-1 or ISO 6508-1 or other equivalent method (e.g. conductivity) and shall achieve the limits specified in 7.2.2.

9.2.4 One liner from every batch of liners shall be tested in accordance with 8.5.3 and meet the minimum design requirements.

9.2.5 A record of the tests carried out shall be kept. Examples of suitable forms of test certificate are shown in Annex A.

9.2.6 In the event of failure to meet test requirements, an investigation into the cause of failure and re-testing shall be performed in accordance with 9.3.

9.3 Failure of liner batch tests

9.3.1 If any of the test results is 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 either

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, or

b) where heat treatment has been shown to be inadequate, liners shall be subjected to re-treatment, and re-tested in accordance with 9.2.2 and 9.2.3. If the results are satisfactory, the batch shall be accepted. This re-treatment may be conducted only once.

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

9.4 Overwrap materials

9.4.1 The supplier's certification 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.

9.4.2 If certification 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 D2291-09 for aramid, and ISO 10618 for carbon fibre or an appropriate equivalent standard.

9.5 Composite cylinder

9.5.1 The inspector shall certify that the design, manufacture, inspection, and testing were carried out in accordance with this part of ISO 11119. An example form of certificate is shown in Annex B.

9.5.2 Each batch of composite cylinders shall be examined and checked to ensure conformity to the design standard. The inspections that shall be performed in accordance with the manufacturer's quality assurance procedures are the following:

a) a visual inspection of external and internal surface finish;

b) dimensions;

c) markings;

d) water capacity;

e) mass;

f) cleanliness.

9.5.3 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 ISO 4706, ISO 10460, ISO 10464, ISO 18172-2, ISO 20703, and EN 14638-3 contain internal surface inspection criteria for guidance on possible defects in metallic liners.

9.5.4 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.

9.5.5 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, none of the five batches shall be released until the investigation carried out in accordance with 8.5.6 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 may 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 after N or N_d cycles, where:

$N = y \times 250$ cycles per year of design life;

$N_d = y \times 500$ cycles per year of design life;

y = 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.

9.5.6 One cylinder per batch of finished cylinders shall be subjected to a burst test in accordance with 8.5.5.

The cylinder subjected to the pressure cycle test (see 9.5.5) may be used for this test.

The burst pressure, P_b, shall be in accordance with the criteria for the cylinder burst test specified in 8.5.5 for the relevant fibre.

NOTE It can be instructive to compare the results of the hydraulic burst test (see 8.5.5) on the prototype test cylinders, the design variant test cylinders, and the production test cylinders.

If the results of the hydraulic burst test (see 8.5.5) from the design variant testing and production testing are consistently less than 85 % of the minimum of the burst tests obtained during prototype testing, the inspection body may wish to determine the cause of the variation.

9.6 Cylinder failure during type approval or batch testing

9.6.1 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 performed.

9.6.2 If there is evidence of a fault in performing 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.

9.6.3 If the test has been performed in a satisfactory manner either

a) the cause of failure shall be identified and the procedure detailed in 9.6.4 or 9.6.5 shall be followed, or

b) the batch shall be rejected and made unserviceable.

9.6.4 If the cause of failure is identified, the defective cylinders may 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.

9.6.5 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 8.5.5 or 8.5.6 (as applicable) for the original batch.

9.6.6 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 part of ISO 11119 shall be permanently and legibly marked in accordance with ISO 13769, except that the empty weight shall be the nominal mass.

Requirements for marking in relevant regulations override the requirements given in this part of ISO 11119.

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 the following:

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 HAS BEEN QUALIFIED WITH A <<Named>> PRESSURE RELIEF DEVICE'**, where a cylinder is approved with a specific pressure relief device (see 8.5.11);

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) the details of components that are permanently attached to the cylinder and form part of the qualified design (e.g. neck rings, protective boots, etc.) with instructions that they shall not be removed at periodic inspection;

e) other additional markings such as re-test dates (in accordance with national legislation), customer names, etc.;

f) the designated life of the cylinder.

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

Annex A
(informative)

Examples of design approval certificate

Design approval certificate – composite cylinders with load sharing metal liners

Issued by……(*Relevant authority*)…… on the basis of applying ISO 11119-4: *Gas cylinders – Refillable composite gas cylinders – Fully wrapped fibre reinforced composite cylinders up to 150 l with welded load sharing metal liners*.

Approval No……
Date……

C ylinder description……(*Family of cylinders which has received type approval*)……

Manufacturer's Drawing No……

Design life…… Underwater…… Special torque……Pressure relief device……

Liner heat treatment……

Liner Welding Details……

Details……

Finished cylinder		Liner		Composite material	
Capacity	l	Material		Fibre(s)	
Test pressure	bar	Min. thickness	mm	Fibre(s) tensile strength	MPa
Diameter	mm	Min. yield strength	MPa	Fibre(s) modulus	GPa
Length	mm	Min. tensile strength	MPa	Matrix components	
Thread		Elongation	%		
Autofrettage pressure	bar	Min. burst pressure	bar	Thickness	mm
Minimum Burst Pressure	bar	Calculated proof pressure	bar		

Compatible Gases:……

Manufacturer or agent…… (*Name and address of manufacturer or its agent*)……

……

……

Type of approval mark……

Details of the results of the examination of the design for design approval are detailed in Type approval Test Report……

The average cylinder burst pressure obtained during the design approval was……bar.

All information may be obtained from……(*Name and address of the approving body*)……

……

Date……
Pla ce……

Signature……

Annex B
(informative)

Specimen test reports

VERIFICATION BODIES REPORT ON:

THE MANUFACTURE OF FULLY-WRAPPED FIBRE REINFORCED COMPOSITE GAS CYLINDERS WITH LOAD-SHARING WELDED LINERS

_____

Approved Inspection Body _____

Approved Inspection Body'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 (in kg) Minimum _____ Maximum _____ Without valve

Minimum _____ Maximum _____ With valve

Each liner was produced by an approved process in accordance with 6.1 heat treated by an appropriate method and checked for hardness. The results of the mechanical tests have been found satisfactory (see 9.1).

Overwrap was applied by wrapping under controlled tension.

Filament Glass Carbon Aramid

designated _____

supplied by _____

impregnated with resin

designated

manufactured by _____

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

Filaments strand strength and reinforcement were verified and found satisfactory.

Each welded liner was subjected to an integrity test (see 8.5.4).

% of the liners were NDT tested.

Each cylinder was subjected to an autofrettage pressure of _____ bar for approximately

_____ (if appropriate)

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 the Standard (see Clause 10).

WE HEREBY CERTIFY that each of the above cylinders meets in full the requirements of the standard.

For and on behalf of the manufacturer _____

For and on behalf of the Approved Inspection Body _____

Specimen test reports (continued)

1. Mechanical tests on liners

Batch No. Code	Test piece dimensions mm	0,2 % yield strength MPa	Tensile strength MPa	Elongation %

For and on behalf of _____

the manufacturer

2. Hydraulic volumetric expansion test certificate for composite cylinders

Customer Order No. _____ Tested to a pressure of _____

and conforming to

Manufacturer's No. _____

Container No.	Cast No	Total expansion ml	Permanent expansion	Perm/Total expansion ratio %	Mass full kg	Mass empty kg	Water capacity litres	Test date

Certified by _____ on behalf of _____ Date _____

(for Manufacturer)

Certified by _____ Date _____

(Approved Inspection Body)

Annex C
(normative)

Prototype, design variant, and production testing

Tables C1, C2 and C3 explain the testing regime to be carried out for type approval, batch testing, and tests to be performed on every cylinder.

The inspector shall verify that the tests required in Tables C.1, C.2, and C.3 are carried out satisfactorily.

Table C1 — Composite material

Test	Prototype and design variant testing	Batch testing
Fibre tensile properties (as per 8.5.16)	2 tests	1 test per batch of fibres[a]
Shear properties (as per 8.5.16)	2 tests	Not applicable
[a] Supplier's certification of the material properties may serve as verification of compliance. The strength of fibre shall be not less than what is specified in the documentation listed in 7.2.3.		

Table C2 — Liners

Test	Prototype and design variant testing	Batch
Material verification	Verification of the certificates covering the parent material and NDT testing thereof[a]	
Mechanical properties on finish liner (as per 9.2.1)	1	1 per liner batch
8.5.3 Liner burst test (as per 9.2.3)	1	1 per liner batch
8.5.4 Liner integrity test	100 %[c]	
Visual inspection (as per 9.2 a))	100 %[c]	10 %[b]
Dimensional check (as per 9.2 b), c), d), and f))	On liners selected for destructive testing[b]	
NDT inspection for cylinders with test pressure ≤60 bar (as per 9.2 e))	1	1 per liner batch[b]
NDT inspection for cylinders with test pressure >60 bar (as per 9.2 e))	100 %[c]	
Hardness test (or equivalent) as per 9.2.3.	0/5/100 %[c]	
NOTE The numbers in the table represent the number of liners or cylinders to be subjected to the relevant test.		
[a] Supplier's certification of the material properties may serve as verification of compliance.		
[b] If one unacceptable defect is found, 100 % of the cylinder batch shall be inspected.		
[c] Tests to be carried out by the manufacturer. The inspector has to ensure that tests have been carried out satisfactorily.		

Table C3 — Finished cylinder tests

Inspections and tests	Prototype and design variant testing	Batch testing
9.5.2 a) Visual inspection	100 %	10 %[c]
9.5.2 b) Dimensional check	100 %	10 %[c]
9.5.2 d) Weight check	100 %	10 %[c]
9.5.2 e) Water capacity	100 %	10 %[c]
10 Marking compliance	100 %	
8.5.1 Proof pressure test or 8.5.2 Hydraulic volumetric expansion[a]	100 %	
8.5.5 Hydraulic burst test	3	1 per batch
8.5.6 Ambient cycle test	2	Minimum of 1 per 5 batches
8.5.7 Environmental cycle test	1	Not applicable
8.5.8 Flaw test	2	Not applicable
8.5.9 Drop test	2	Not applicable
8.5.10 High velocity impact (gunfire) test	1	Not applicable
8.5.11 Fire resistance test[d]	2	Not applicable
8.5.12 Salt-water immersion test[b]	2	Not applicable
8.5.13 Torque test	1	Not applicable
8.5.14 Environmentally assisted stress rupture test[e]	2	Not applicable
8.5.15 Leak test	2	100 %

NOTE The numbers in the table represent the number of cylinders that shall be subjected to the relevant test.

[a] Applicable only if test 8.5.1 is not performed.

[b] Test 8.5.12 is optional, except for diving applications where it is required.

[c] If one unacceptable defect is found, 100 % of the cylinder batch shall be inspected.

[d] Test 8.5.11 is optional, except if pressure relief devices are fitted.

[e] Test 8.5.14 is optional, except when the glass or aramid fibre has a load-sharing application.

Bibliography

[1] UN Recommendations on the Transport of Dangerous Goods – Model Regulations (as amended)

[2] ISO 10460, *Gas cylinders — Welded carbon-steel gas cylinders — Periodic inspection and testing*

[3] ISO 10464, *Gas cylinders — Refillable welded steel cylinders for liquefied petroleum gas (LPG) — Periodic inspection and testing*

[4] ISO 11623, *Transportable gas cylinders — Periodic inspection and testing of composite gas cylinders*

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