



BSI Standards Publication

Gas cylinders — High pressure cylinders for the on-board storage of natural gas as a fuel for automotive vehicles

National foreword

This British Standard is the UK implementation of EN ISO 11439:2013+A1:2021. It is identical to [ISO 11439:2013](#), incorporating amendment 1:2021. It supersedes BS EN ISO 11439:2013, which is withdrawn.

The start and finish of text introduced or altered by amendment is indicated in the text by tags. Tags indicating changes to ISO text carry the number of the ISO amendment. For example, text altered by ISO amendment 1 is indicated by **A1** **A1**.

The UK participation in its preparation was entrusted to Technical Committee PVE/3/3, Transportable Gas Containers - Cylinder Design, Construction and Testing at the Time of Manufacture.

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

The UK committee advises users that amendment 1:2021 to [ISO 11439:2013](#) was initially prompted by multiple in-service failures of gas cylinders due to vehicle fires and external corrosion. An optional corrosion resistance test has now been introduced as Annex H, and it is the UK committee's view that once cylinder manufacturers have had an opportunity to evaluate the performance of their designs using this optional test, it may become a normative test in a future version of this standard.

Furthermore, users are advised that an improved fire test method based on the localized fire test in the United Nations Economic Commission for Europe (UNECE) Global Technical Regulations (GTRs) for hydrogen vehicles was also considered for incorporation into this amendment. However, the ISO working group decided to delay adopting this test since (at the time of publication of this standard) the UNECE's GTR fire test is undergoing an extensive revision, including round-robin testing by multiple test labs to ensure the proposed new format provides repeatable results.

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Published by BSI Standards Limited 2022

ISBN 978 0 539 04024 1

ICS 23.020.35; 43.060.40

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This British Standard was published under the authority of the Standards Policy and Strategy Committee on 30 June 2013.

Amendments/corrigenda issued since publication

Date	Text affected
31 January 2022	Implementation of ISO amendment 1:2021 with CEN endorsement A1:2021

English Version

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

Bouteilles à gaz - Bouteilles haute pression pour le
stockage de gaz naturel utilisé comme carburant à
bord des véhicules automobiles (ISO 11439:2013)

Gasflaschen - Hochdruck-Flaschen für die
fahrzeuginterne Speicherung von Erdgas als
Treibstoff für Kraftfahrzeuge (ISO 11439:2013)

This European Standard was approved by CEN on 18 April 2013.

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CEN-CENELEC Management Centre: Rue de la Science 23, B-1040 Brussels

European foreword

This document (EN ISO 11439:2013) has been prepared by Technical Committee ISO/TC 58 "Gas cylinders" in collaboration with Technical Committee CEN/TC 23 "Transportable gas cylinders" the secretariat of which is held by BSI.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by December 2013, and conflicting national standards shall be withdrawn at the latest by December 2013.

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Endorsement notice

The text of [ISO 11439:2013](#) has been approved by CEN as EN ISO 11439:2013 without any modification.

European foreword to amendment A1

This document (EN ISO 11439:2013/A1:2021) has been prepared by Technical Committee ISO/TC 58 "Gas cylinders" in collaboration with Technical Committee CEN/TC 23 "Transportable gas cylinders" the secretariat of which is held by BSI.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by May 2022, and conflicting national standards shall be withdrawn at the latest by May 2022.

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Endorsement notice

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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.

ISO 11439 was prepared by Technical Committee ISO/TC 58, *Gas cylinders*, Subcommittee SC 3, *Cylinder design*.

This second edition cancels and replaces the first edition ([ISO 11439:2000](#)), which has been technically revised. In addition to editorial improvements, the principal technical difference between the first and second editions is the clarification and alteration of the “Change of Design” requirements for the various cylinder types.

Introduction

Cylinders for the on-board storage of fuel for natural gas vehicle service are required to be light-weight, at the same time maintaining or improving on the level of safety currently existing for other pressure vessels.

Owners or users of cylinders designed to this International Standard should note that the cylinders are designed to operate safely if used in accordance with specified service conditions for a specified finite service life only. The expiry date is marked on each cylinder and it is the responsibility of owners and users to ensure that cylinders are not used after that date, and that they are inspected in accordance with the manufacturer's instructions.

Users of this International Standard are encouraged to consider the environmental impacts associated with performing certain tests.

Gas cylinders — High pressure cylinders for the on-board storage of natural gas as a fuel for automotive vehicles

1 Scope

This International Standard specifies minimum requirements for light-weight refillable gas cylinders intended only for the on-board storage of high pressure compressed natural gas as a fuel for automotive vehicles to which the cylinders are to be fixed. The service conditions do not cover external loadings that can arise from vehicle collisions, etc.

This International Standard covers cylinders of any seamless steel, seamless aluminium alloy or non-metallic material construction, using any design or method of manufacture suitable for the specified service conditions. This International Standard does not cover cylinders of stainless steel. Although this standard uses 200 bar as a reference working pressure, other working pressures can be used.

Cylinders covered by this International Standard are designated Type 1, Type 2, Type 3 and Type 4.

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 148-1](#), *Metallic materials — Charpy pendulum impact test — Part 1: Test method*

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

[ISO 527-2](#), *Plastics — Determination of tensile properties — Part 2: Test conditions for moulding and extrusion plastics*

[ISO 2808](#), *Paints and varnishes — Determination of film thickness*

[ISO 6506-1](#), *Metallic materials — Brinell hardness test — Part 1: Test method*

[ISO 6892-1](#), *Metallic materials — Tensile testing — Part 1: Method of test at room temperature*

[ISO 7866](#), *Gas cylinders — Refillable seamless aluminium alloy gas cylinders — Design, construction and testing*

[ISO 9227](#), *Corrosion tests in artificial atmospheres — Salt spray tests*

[ISO 9712](#), *Non-destructive testing — Qualification and certification of NDT personnel*

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

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

[ISO 9809-3](#), *Gas cylinders — Refillable seamless steel gas cylinders — Design, construction and testing — Part 3: Normalized steel cylinders*

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

[ISO 15403-1](#), *Natural gas — Natural gas for use as a compressed fuel for vehicles — Part 1: Designation of the quality*

ISO/TR 15403-2, *Natural gas — Natural gas for use as a compressed fuel for vehicles — Part 2: Specification of the quality*

[ISO 15500-13](#), *Road vehicles — Compressed natural gas (CNG) fuel system components — Part 13: Pressure relief device (PRD)*

ASTM D522-93a, *Standard Test Methods for Mandrel Bend Test of Attached Organic Coatings*

[A1](#) ASTM D1308 [A1](#), *Standard Test Method for Effect of Household Chemicals on Clear and Pigmented Organic Finishes*

[A1](#) ASTM D2794 [A1](#), *Standard Test Method for Resistance of Organic Coatings to the Effects of Rapid Deformation (Impact)*

[A1](#) ASTM D3170 [A1](#), *Standard Test Method for Chipping Resistance of Coatings*

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

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

[A1](#) ASTM G154 [A1](#), *Standard Practice for Operating Fluorescent Light Apparatus for UV Exposure of Nonmetallic Materials*

[A1](#) NACE/TM 0177 [A1](#), *Laboratory Testing of Metals for Resistance to Sulfide Stress Cracking and Stress Corrosion Cracking in H₂S Environments*

3 Terms and definitions

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

3.1

authorized inspection body

authorized inspection body, approved or recognized by the regulatory authority of the user country, for the supervision of construction and testing of cylinders used for the on-board storage of natural gas

3.2

autofrettage

pressure application procedure used in manufacturing composite cylinders with metal liners, which strains the liner past its yield point sufficient to cause permanent plastic deformation

3.3

autofrettage pressure

pressure within the overwrapped cylinder at which the required distribution of stresses between the liner and the overwrap is established

3.4

batch – composite cylinders

group of not more than 200 cylinders plus cylinders for destructive testing, or if greater, one shift of successive production of cylinders, successively produced from qualified liners having the same size, design, specified materials of construction and process of manufacture

3.5

batch – metal cylinders/liners

group of not more than 200 cylinders/liners plus cylinders/liners for destructive testing, or if greater, one shift of successive production of metal cylinders/liners, successively produced having the same nominal diameter, wall thickness, design, specified material of construction, material cast, process of manufacture, equipment for manufacture and heat treatment, and conditions of time, temperature and atmosphere during heat treatment

3.6

batch – non-metallic liners

group of not more than 200 liners plus liners for destructive testing, or if greater, one shift of successive production of non-metallic liners, successively produced having the same nominal diameter, wall thickness, design, specified material of construction and process of manufacture

3.7

burst pressure

highest pressure reached in a cylinder during a burst test

3.8

composite cylinder

cylinder made of resin-impregnated continuous filament wound over a metallic or non-metallic liner

3.9

destroyed

cylinder in a state of alteration which makes it physically unusable for its purpose

3.10

finished cylinders

completed cylinders which are ready for use, complete with identification marks and external coating including integral insulation and/or protection as specified by the manufacturer on the design drawing for the cylinder

3.11

liner

inner portion of the composite cylinder, comprising of a metallic or non-metallic vessel

3.12

manufacturer

person or organization responsible for the design, fabrication and testing of the cylinders

3.13

overwrap

reinforcement system of filament and resin applied over the liner

3.14

pre-stress

process of applying autofrettage or controlled tension winding

3.15

service life

life, in years, during which the cylinders can be used in accordance with the standard service conditions

3.16

settled pressure

gas pressure when a given settled temperature is reached

3.17

settled temperature

uniform gas temperature in the cylinder after the dissipation of any heat caused by filling

3.18

test pressure

required pressure applied during a pressure test

3.19

type 1 design

an all metal cylinder

3.20

type 2 design

a hoop wrapped cylinder with a load sharing metal liner and composite reinforcement on the cylindrical part only

3.21

type 3 design

a fully wrapped cylinder with a load sharing metal liner and composite reinforcement on both the cylindrical part and dome ends

3.22

type 4 design

a fully wrapped cylinder with a non-load sharing liner and composite reinforcement on both the cylindrical part and dome ends

3.23

working pressure

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

4 Service conditions

4.1 General

4.1.1 Standard service conditions

The standard service conditions specified in this clause are provided as the basis for the design, manufacture, inspection, testing and approval of cylinders that are to be mounted permanently on vehicles and used to store natural gas at ambient temperatures for use as a fuel on the vehicles.

4.1.2 Service life

The service life for which cylinders are safe shall be specified by the cylinder manufacturer on the basis of use under service conditions specified herein. The maximum service life shall be 20 years.

4.2 Maximum pressures

This International Standard is based upon a working pressure of 200 bar settled at 15 °C for natural gas as a fuel with a maximum filling pressure of 260 bar. Other working pressures may be accommodated by adjusting the pressure by the appropriate factor (ratio); e.g. a 240 bar working pressure system will require pressures to be multiplied by 1,20. See also [Annex E](#).

Except where pressures have been adjusted in this way, the cylinder shall be designed to be suitable for:

- a) a pressure of 200 bar at a settled temperature of 15 °C;
- b) a maximum pressure shall not exceed 260 bar, regardless of filling conditions or temperature.

4.3 Design number of filling cycles

Cylinders shall be designed to be filled up to 1 000 times per year of service.

4.4 Temperature range

4.4.1 Settled gas temperature

Settled temperature of gas in cylinders, which may vary from a minimum of -40 °C to a maximum of +65 °C.

4.4.2 Cylinder temperatures

Cylinders shall be designed for service conditions involving temperatures of between $-40\text{ }^{\circ}\text{C}$ and $+82\text{ }^{\circ}\text{C}$. Cylinder material temperatures over $+65\text{ }^{\circ}\text{C}$ are expected to be sufficiently local, or of short enough duration, that the temperature of gas in the cylinder never exceeds $+65\text{ }^{\circ}\text{C}$, except under the conditions of [4.4.3](#).

4.4.3 Transient temperatures

Developed gas temperatures in the cylinders during filling and discharge may vary beyond the limits of [4.4.1](#).

4.5 Gas composition

4.5.1 General

Cylinders shall be designed to tolerate being filled with natural gas meeting the specification of [ISO 15403-1](#) and ISO/TR 15403-2, and either of dry gas or wet gas as described in [4.5.2](#) or [4.5.3](#), respectively. Methanol and/or glycol shall not be deliberately added to the natural gas.

NOTE Where it is suspected that wet-gas conditions may exist, it has been found that a minimum of 1 mg of compressor oil per kg of gas has prevented the corrosion of steel cylinders.

4.5.2 Dry gas

Water vapour shall be limited to less than 32 mg/m^3 (i.e. a pressure dewpoint of $-9\text{ }^{\circ}\text{C}$ at 200 bar). Constituent maximum limits shall be:

Hydrogen sulfide and other soluble sulfides	23 mg/m^3
Oxygen	1 % (volume fraction)
Hydrogen, when cylinders are manufactured from a steel with an ultimate tensile strength exceeding 950 MPa	2 % (volume fraction)

4.5.3 Wet gas

For gas that has a higher water content than that of dry gas, constituent limits shall be:

Hydrogen sulfide and other soluble sulfides	23 mg/m^3 maximum
Oxygen	1 % (volume fraction) maximum
Carbon dioxide	3 % (volume fraction) maximum
Hydrogen	0,1 % (volume fraction) maximum
Compressor oil	1 mg/kg natural gas minimum (see Note 4.5.1)

4.6 External surfaces

It is not necessary for cylinders to be designed for continuous exposure to mechanical or chemical attack (e.g. leakage from cargo that may be carried on vehicles or severe abrasion damage from road conditions). However, cylinder external surfaces shall be designed to withstand inadvertent exposure to mechanical or chemical attack consistent with their installation being carried out in accordance with the instructions to be provided with the cylinder.

Mechanical or chemical attack may result from environments such as:

- a) water, either by intermittent immersion or road spray;

- b) salt, due to the operation of the vehicle near the ocean or where ice-melting salt is used;
- c) ultraviolet radiation from sunlight;
- d) impact of gravel;
- e) solvents, acids and alkalis, fertilizers;
- f) automotive fluids, including petrol, hydraulic fluids, battery acid, glycol and oils;
- g) exhaust gases.

5 Inspection and testing

Evaluation of conformity can be carried out in accordance with the relevant regulations recognized by the country(ies) where the cylinders are intended to be used.

To ensure that cylinders are in conformance to this International Standard, they shall be subject to inspection and testing in accordance with [Clauses 7, 8, 9, or 10](#) and [Annex A](#) as appropriate to the construction. This shall be carried out by an authorized inspection body, hereafter referred to as “the Inspector”, recognized in the countries of use. The Inspector shall be competent for inspection of cylinders.

6 Type approval procedure

6.1 General

Type approval consists of two parts:

- a) design approval, comprising submission of information by the manufacturer to the Inspector, as detailed in [6.3](#).
- b) prototype testing, comprising testing carried out under the supervision of the Inspector. The cylinder material, design, manufacture and examination shall be proved to be adequate for their intended service by meeting the requirements of the prototype tests specified in [7.5, 8.5, 9.5](#) or [10.5](#), and [Annex A](#), as appropriate for the particular cylinder design.

The test data shall also document the dimensions, wall thicknesses and weights of each of the test cylinders.

6.2 Type approval

Cylinder designs shall be approved by the Inspector. Information shall be submitted by the manufacturer with a request to the Inspector for approval, and shall include:

- a) statement of service, in accordance with [6.3](#);
- b) design data, in accordance with [6.4](#);
- c) manufacturing data, in accordance with [6.5](#);
- d) fracture performance and NDE defect size, in accordance with [6.6](#);
- e) specification sheet, in accordance with [6.7](#);
- f) additional supporting data, in accordance with [6.8](#).

6.3 Statement of service

The purpose of the statement of service is to guide users and installers of cylinders as well as to inform the Inspector. The statement of service shall include:

- a) a statement that the cylinder design is suitable for use in the service conditions defined in [Clause 4](#) for the service life of the cylinder;
- b) a statement of the service life;
- c) the minimum periodic inspection requirements;
- d) a specification for the pressure relief devices, and insulation if provided;
- e) a specification for the support methods, protective coatings and any other items required but not provided;
- f) a description of the cylinder design;
- g) any other information and instructions necessary to ensure the safe use and inspection of the cylinder.

6.4 Design data

6.4.1 Drawings

Drawings shall include, as a minimum:

- a) title, manufacturer, reference number, date of issue, and revision numbers with dates of issue if applicable;
- b) reference to this International Standard and the cylinder type;
- c) all cylinder dimensions complete with tolerances, including details of end closure shapes, openings, and neck threads;
- d) water capacity and mass (including any permanent attachments), complete with tolerance, of cylinders;
- e) material specifications, mechanical properties (including tolerances where applicable) and, for metal cylinders or metal liners, the specified hardness range;
- f) other data such as, working pressure, autofrettage pressure, test pressure, minimum design burst pressure, design life;
- g) details of the fire protection system and of any exterior protective coating.

6.4.2 Stress analysis report

A finite element stress analysis or other stress analysis shall be carried out. A table summarizing the calculated stresses shall be provided.

6.4.3 Material property data

A description of the materials and tolerances of the material properties used in the design shall be provided. Test data shall also be presented characterizing the mechanical properties and the suitability of the materials for service under the conditions specified in [Clause 4](#).

6.4.4 Fire protection

The arrangement of pressure relief devices, and insulation if provided, that will protect the cylinder from sudden rupture when exposed to the fire conditions in A.15 shall be specified. Test data shall substantiate the effectiveness of the specified fire protection system.

NOTE A manufacturer may specify alternative PRD locations for specific vehicle installations.

6.5 Manufacturing data

Details of fabrication processes, non-destructive examinations, production tests and batch tests shall be provided. Production processes such as heat treatment, end forming, resin-mix ratio, filament tension and speed for controlled tension winding, curing times and temperatures, and autofrettage procedures shall be specified.

Surface finish, thread details, acceptance criteria for ultrasonic examination (or equivalent), and maximum lot sizes for batch tests shall also be specified.

6.6 Fracture performance and non-destructive examination (NDE) defect size

The manufacturer shall specify the maximum defect size for non-destructive examination that will ensure leak before break (LBB) fracture performance, and will prevent failure by leakage or rupture of the cylinder during its service life. The maximum defect size shall be established by a method suitable to the design.

NOTE An example of a suitable method is given in [Annex C](#).

6.7 Specification sheet

A summary of the documents providing the information required in [6.2](#) shall be listed on a specification sheet for each cylinder design. The title, reference number, revision numbers and dates of original issue and version issues of each document shall be given. All documents shall be signed or initialled by the issuer.

6.8 Additional supporting data

Additional data that would support the application may be provided.

6.9 Type approval certificate

If the results of the type approval according to [6.1](#) and the prototype testing according to [7.5](#), [8.5](#), [9.5](#) or [10.5](#), and [Annex A](#), as appropriate to the particular cylinder design, are satisfactory, the Inspector shall issue a test type approval certificate.

NOTE An example of a type approval certificate is given in [Annex D](#).

7 Requirements for type 1 metal cylinders

7.1 General

This International Standard does not provide design formulae, nor list permissible stresses or strains, but requires the adequacy of the design to be established by appropriate calculations and demonstrated by testing to show that cylinders shall pass the materials, design qualification, production and batch tests specified.

The design shall ensure a “leak-before-break” failure mode during normal service.

7.2 Materials

7.2.1 General requirements

Materials used shall be suitable for the service conditions specified in [Clause 4](#). The design shall not have incompatible materials in contact with each other.

7.2.2 Controls on chemical composition

7.2.2.1 Steel

Steels shall be aluminium- and/or silicon-killed. The chemical composition of all steels shall be declared and defined at least by:

- a) the carbon, manganese, aluminium and silicon contents in all cases;
- b) the chromium, nickel, molybdenum, boron and vanadium contents, and that of any other alloying elements intentionally added.

The sulfur and phosphorus content in the cast analysis shall not exceed the values given in [Table 1](#).

Table 1 — Maximum sulfur and phosphorus limits

sulfur	0,010 % by mass
phosphorus	0,020 % by mass
sulfur + phosphorus	0,025 % by mass

7.2.2.2 Aluminium

Aluminium alloys may be used to produce cylinders provided that they meet all requirements of this International Standard and have maximum lead and bismuth contents not exceeding 0,003 %.

NOTE A list of registered alloys is maintained by the Aluminium Association Inc.¹⁾ and can be found under the "International Registration Records", entitled "International Alloy Designations and Chemical Composition Limits for Wrought Aluminium and Wrought Aluminium Alloys".

7.3 Design Requirements

7.3.1 Test pressure

The minimum test pressure used in manufacture shall be 1,5 times working pressure.

7.3.2 Burst pressure

The minimum burst pressure shall be not less than 2,25 times working pressure.

7.3.3 Stress analysis

The stresses in the cylinder shall be calculated for the working pressure, test pressure and design burst pressure. The calculations shall use suitable analysis to establish stress distributions to justify the minimum design wall thicknesses.

7.3.4 Maximum defect size

The maximum defect size at any location in the metal cylinder such that the cylinder meets pressure cycling and LBB requirements, shall be specified.

1) Aluminum Association Inc., 900 19th Street N.W., Washington D.C., 20006-2168, USA

The allowable defect size for NDE shall be determined by an appropriate method, e.g. as described in [Annex C](#).

7.3.5 Openings

The centre line of openings shall coincide with the longitudinal axis of the cylinder.

7.3.6 Fire protection

The cylinder design shall be protected with pressure relief devices. The cylinder, its materials, pressure relief devices (PRD) and any added insulation or protective material shall be designed collectively to ensure adequate safety during fire conditions in the test specified in A.15. A manufacturer may specify alternative PRD locations for specific vehicle installations in order to optimize safety considerations.

Pressure relief devices shall conform to [ISO 15500-13](#).

7.3.7 Attachments

When a neck ring, foot ring or an attachment for support is provided, it shall be of material compatible with that of the cylinder and shall be securely attached by a method other than welding, brazing or soldering.

7.4 Construction and workmanship

7.4.1 End closure

Each cylinder shall be examined for thickness and surface finish before end forming operations are carried out. The base ends of aluminium cylinders shall not be sealed by a forming process. The base ends of steel cylinders that have been closed by forming shall be NDE inspected or equivalent after closure. Metal shall not be added in the process of closure at the ends.

7.4.2 Heat treatment

After end forming the cylinders shall be heat treated to the hardness range specified for the design. Localized heat treatment shall not be used.

7.4.3 Neck threads

Threads shall be clean cut, even, without surface discontinuities, to gauge and conform to International Standards.

7.4.4 Exterior environmental protection

Exterior protection may be provided. Examples of exterior protection methods are:

- a) a surface finish giving adequate protection (e.g. metal sprayed on to aluminium, anodizing); or
- b) a protective coating (e.g. organic coating, paint); if exterior coating is part of the design as specified by the manufacturer the requirements of A.9 shall be met.

Any coatings applied to cylinders shall be such that the application process does not adversely affect the mechanical properties of the cylinder. The coating shall be designed to facilitate subsequent in-service inspection and the manufacturer shall provide guidance on coating treatment during such inspection in order to ensure the continued integrity of the cylinder.

7.4.5 Traceability

Materials of construction affecting cylinder performance, as determined by the manufacturer, shall be traceable to the extent required to recall cylinders, if necessary.

7.5 Prototype testing procedure

7.5.1 General requirements

Prototype testing shall be conducted on each new design, on finished cylinders that are representative of normal production and complete with permanent identification marks. The test cylinders shall be selected and the prototype tests specified in 7.5.2 (and detailed in [Annex A](#)) verified by the Inspector. If more cylinders are subjected to the tests than are required by this International Standard, all results shall be documented.

7.5.2 Prototype tests

7.5.2.1 Tests required

The Inspector shall select the necessary cylinders for testing and verify:

- a) the tests specified in 7.5.2.2 or 7.5.2.3 (material tests) on one cylinder;
- b) the test specified in 7.5.2.4 (hydrostatic pressure burst test) on three cylinders;
- c) the test specified in 7.5.2.5 (ambient temperature pressure cycling test) on two cylinders;
- d) the test specified in 7.5.2.6 (LBB test) on three cylinders;
- e) the test specified in 7.5.2.7 (bonfire test) on one or two cylinders, as appropriate;
- f) the test specified in 7.5.2.8 (penetration test) on one cylinder.

7.5.2.2 Material tests for steel cylinders

- a) Tensile test

Steel from a finished cylinder shall meet the requirements of the tensile test in A.1.

- b) Impact test

Steel from a finished cylinder shall meet the requirements of the impact test in A.2.

- c) Sulfide stress cracking resistance test

If the upper limit of the specified tensile strength for the steel exceeds 950 MPa, the steel from a finished cylinder shall meet the requirements of the sulfide stress cracking resistance test in A.3. $\boxed{A_1}$ The actual tensile strength of the steel according to A.1 shall not exceed the value obtained by more than 5 % on the samples tested for sulfide stress cracking resistance. $\boxed{A_1}$

7.5.2.3 Material tests for aluminium alloy cylinders

- a) Tensile test

Aluminium alloy from a finished cylinder shall meet the requirements of the tensile test in A.1.

- b) Corrosion tests

Aluminium alloy from a finished cylinder shall meet the requirements of the corrosion tests in A.4.

- c) Sustained load cracking tests

Aluminium alloy from a finished cylinder shall meet the requirements of the sustained load cracking tests in A.5.

7.5.2.4 Hydrostatic pressure burst test

Three representative cylinders shall be hydrostatically pressurized to failure in accordance with A.12. The cylinder burst pressures shall exceed the minimum burst pressure calculated by the stress analysis for the design, and shall be at least 2,25 times working pressure. The fracture shall initiate in the cylindrical part of the cylinder, and the cylinder shall remain in one piece.

7.5.2.5 Ambient temperature pressure cycling test

Two cylinders shall be pressure cycled at ambient temperature in accordance with A.13. The cylinders shall not fail before reaching the specified service life in years multiplied by 1 000 cycles. Cylinders that complete the test shall be destroyed.

7.5.2.6 Leak-before-break (LBB) test

Three cylinders shall be tested in accordance with A.6.

7.5.2.7 Bonfire test

One or two cylinders, as appropriate, shall be tested in accordance with A.15.

7.5.2.8 Penetration test

One cylinder shall be tested in accordance with A.16.

7.5.3 Change of design

A design change is a dimensional change not attributable to normal manufacturing tolerances, or any change in the selection of structural materials. Design changes may be qualified through a reduced test programme. Changes of design specified in [Table 2](#) shall require only the prototype testing as specified in the table.

Table 2 — Change of design for type 1 cylinders

Design change	Type of test				
	Hydrostatic burst	Pressure cycling at ambient temperature	LBB	Bonfire	Penetration
	Clause				
	A.12	A.13	A.6	A.15	A.16
Metallic cylinder material ^d	X	X	X	X	X
Diameter change ≤ 20 %	X	X			
Diameter change > 20 %	X	X	X	X	X
Length change ≤ 50 %	X			X ^a	
^a Test only required when length increases. ^b Only when thickness change proportional to diameter and/or pressure change. ^c Only required for non- ISO 9809-1 designs. ^d Materials tests are also required.					

Design change	Type of test				
	Hydrostatic burst	Pressure cycling at ambient temperature	LBB	Bonfire	Penetration
Length change > 50 %	X	X		X ^a	
Working pressure change ≤ 20 % ^b	X	X			
Dome shape	X	X	X ^c		
Opening size	X	X			
Pressure relief device				X	
^a Test only required when length increases. ^b Only when thickness change proportional to diameter and/or pressure change. ^c Only required for non-ISO 9809-1 designs. ^d Materials tests are also required.					

7.6 Batch tests

7.6.1 General requirements

Batch testing shall be conducted on finished cylinders that are representative of normal production and are complete with permanent identification marks. The cylinders required for testing shall be randomly selected from each batch. If more cylinders are subjected to the tests than are required by this International Standard, all results shall be documented. Heat treated samples shown to be representative of finished cylinders may also be used.

Cylinders qualified in accordance with [ISO 9809-1](#), [ISO 9809-2](#), [ISO 9809-3](#) or [ISO 7866](#) are not required to perform the pressure cycling test described in [7.6.2.2](#).

7.6.2 Required tests

7.6.2.1 Batch tests

Tests shall be carried out on each batch of cylinders:

- a) on one cylinder, one hydrostatic pressure burst test in accordance with A.12.
 - b) on a further cylinder, or a heat treated witness sample representative of a finished cylinder:
 - 1) a check of the critical dimensions against the design (see [6.4.1](#));
 - 2) one tensile test in accordance with A.1; the test results shall satisfy the requirements of the design (see [6.4.1](#));
 - 3) for steel cylinders, three impact tests in accordance with A.2; the test results shall satisfy the requirements specified in A.2;
- A1** Text deleted **A1**
- A1** 4) **A1** when a protective coating is a part of the design, a coating batch test in accordance with A.24. Where the coating fails to meet the requirements of A.24, the batch shall be 100 % inspected to remove cylinders with similar defective coatings. The coating on all defectively coated cylinders may be stripped and recoated. The coating batch test shall then be repeated.

All cylinders represented by a batch test and which fail to meet the specified requirements shall follow the procedures specified in [7.9](#).

7.6.2.2 Pressure cycling test

A pressure cycling test shall be carried out on finished cylinders in accordance with A.13 at a test frequency defined as:

- a) initially, one cylinder from each batch shall be pressure cycled for a total of 1 000 times the specified service life in years, with a minimum 15 000 cycles;
- b) if on 10 sequential production batches of a design family (i.e. similar materials and processes within the definition of a minor design change, see 7.5.3), none of the pressure cycled cylinders in 7.6.2.2a) leaks or ruptures in less than 1 500 cycles multiplied by the specified life in years (minimum 22 500 cycles), the pressure cycle test may be reduced to one cylinder from every five batches of production;
- c) if on 10 sequential production batches of a design family, none of the pressure cycled cylinders in 7.6.2.2a) leaks or ruptures in less than 2 000 cycles multiplied by the specified service life in years (minimum 30 000 cycles), the pressure cycle test may be reduced to one cylinder from every 10 batches of production;
- d) should more than three months have expired since the last pressure cycle test, then a cylinder from the next batch of production shall be pressure cycle tested in order to maintain the reduced frequency of batch testing in 7.6.2.2b) or 7.6.2.2c);
- e) should any reduced frequency pressure cycle test cylinder in 7.6.2.2b) or 7.6.2.2c) fail to meet the required number of pressure cycles (minimum 22 500 or 30 000 pressure cycles, respectively), it shall be necessary to repeat the batch pressure cycle test frequency in 7.6.2.2a) for a minimum of 10 production batches to re-establish the reduced frequency of batch pressure cycle testing in 7.6.2.2b) or 7.6.2.2c).

Should any cylinder in 7.6.2.2a), 7.6.2.2b) or 7.6.2.2c) fail to meet the minimum cycle life requirement of 1 000 cycles multiplied by the specified service life in years (minimum 15 000 cycles), the cause of failure shall be determined and corrected following the procedures in 7.9. The pressure cycle test shall then be repeated on an additional three cylinders from that batch. Should any of the three additional cylinders fail to meet the minimum pressure cycling requirement of 1 000 cycles multiplied by the specified service life in years, the batch shall be rejected.

7.7 Tests on every cylinder

Production examinations and tests shall be carried out on each cylinder produced in a batch, either during manufacture or after completion, as appropriate:

- a) by NDE in accordance with [Annex B](#) or proven equivalent method to verify that the maximum defect size does not exceed the size specified in the design as determined in accordance with [7.3.4](#). The NDE method shall be capable of detecting the maximum defect size allowed;
- b) to verify that the critical dimensions and mass of the completed cylinders are within design tolerances;
- c) to verify conformance to specified surface finish with special attention to deep drawn surfaces and folds or laps in the neck or shoulder of forged or spun end enclosures or openings;
- d) to verify the permanent identification marks;
- e) by hardness tests of heat treated cylinders in accordance with A.8; the values thus determined shall be in the range specified for the design;
- f) by hydrostatic test of finished cylinders in accordance with A.11. If volumetric expansion test is chosen, the manufacturer shall establish the appropriate limit of permanent expansion for the test pressure used, but in no case shall the permanent expansion exceed 10 % of the total volumetric expansion measured under the test pressure;

- g) by leak testing of cylinders with base ends formed by spinning. Typical testing procedures include the pneumatic leakage test where the bottom end should be clean and free from all moisture on the test pressure side. The inside area of the cylinder bottom surrounding the closure should be subjected to a pressure equal to at least $2/3$ times the test pressure of the cylinder for a minimum of 1 min. This area should be not less than 20 mm in diameter around the closure and at least 6 % of the total bottom area. The opposite side should be covered with water or another suitable medium and closely examined for indication of leakage. Cylinders that leak should be rejected. Other test procedures include a low pressure pneumatic test, and a helium leak test.

7.8 Batch acceptance certificate

If the results of batch testing according to [7.6](#) and [7.7](#) are satisfactory, the manufacturer and the Inspector shall sign an acceptance certificate.

NOTE An example of an acceptance certificate (referred to as a “Report of Manufacture and Certificate of Conformance”) is given in [Annex D](#).

7.9 Failure to meet test requirements

In the event of failure to meet test requirements, re-testing or re-heat treatment and re-testing shall be carried out:

- a) if there is evidence of a fault in carrying out a test, or an error of measurement, a further test shall be performed; if the result of this test is satisfactory, the first test shall be ignored;
- b) if the test has been carried out in a satisfactory manner, the cause of test failure shall be identified.

If the failure is considered to be due to the heat treatment applied, the manufacturer may subject all the cylinders implicated by the failure to a further heat treatment, i.e. if the failure is in a test representing the prototype or batch cylinders, test failure shall require re-heat treatment of all the represented cylinders prior to re-testing.

Whenever cylinders are re-heat treated, the minimum guaranteed wall thickness shall be maintained.

Only the relevant prototype or batch tests needed to prove the acceptability of the new batch shall be performed again. If one or more tests prove even partially unsatisfactory, all cylinders of the batch shall be rejected and not placed in service.

If the failure is due to a cause other than the applied heat treatment, all defective cylinders shall be either rejected or repaired by an approved method. Provided that the repaired cylinders pass the test(s) required for the repair, they shall be re-instated as part of the original batch.

8 Requirements for type 2 hoop-wrapped cylinders

8.1 General

This International Standard does not provide design formulae nor list permissible stresses or strains, but requires the adequacy of the design to be established by appropriate calculations and demonstrated by testing to show that cylinders shall pass the materials, design qualification, production and batch tests specified in this International Standard.

During pressurization, this type of cylinder design exhibits behaviour in which the displacements of the composite overwrap and the metal liner are superimposed.

The design shall ensure a “leak-before-break” failure mode during normal service.