

INTERNATIONAL STANDARD

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11439

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

*Bouteilles à gaz — Bouteilles haute pression pour le stockage de gaz
naturel utilisé comme carburant à bord des véhicules automobiles*



Reference number
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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 3.

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 International Standard may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

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

Annexes A and B form a normative part of this International Standard. Annexes C to H are for information only.

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. These requirements are achieved by:

- a) specifying service conditions precisely and comprehensively as a firm basis for both cylinder design and use;
- b) using an appropriate method to assess cyclic pressure fatigue life and to establish allowable defect sizes in metal cylinders or liners;
- c) requiring design qualification tests;
- d) requiring non-destructive testing and inspection of all production cylinders;
- e) requiring destructive tests on cylinders and cylinder material taken from each batch of cylinders produced;
- f) requiring manufacturers to have a comprehensive quality system documented and implemented;
- g) requiring periodic re-inspection and, if necessary, retesting in accordance with the manufacturer's instructions;
- h) requiring manufacturers to specify as part of their design, the safe service life of their cylinders.

Cylinder designs that meet the requirements of this International Standard:

- a) will have a fatigue life which exceeds the specified service life;
- b) when pressure cycled to failure, will leak but not rupture;
- c) when subject to hydrostatic burst tests, will have factors of "stress at burst pressure" over "stress at working pressure" that exceed the values specified for the type of design and the materials used.

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.

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 serially produced 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 which may arise from vehicle collisions, etc.

This International Standard covers cylinders of any steel, aluminium 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 or of welded construction.

Cylinders covered by this International Standard are designated as follows:

CNG-1	Metal
CNG-2	Metal liner reinforced with resin impregnated continuous filament (hoop wrapped)
CNG-3	Metal liner reinforced with resin impregnated continuous filament (fully wrapped)
CNG-4	Resin impregnated continuous filament with a non-metallic liner (all composite)

NOTE Cylinders designed in accordance with ISO 9809-1, ISO 9809-2, ISO 9809-3 and ISO 7866 can be used for this service provided these designs meet additional requirements as specified in this International Standard.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 148:1983, *Steel — Charpy impact test (V-notch)*.

ISO 306:1994, *Plastics — Thermoplastic materials — Determination of Vicat softening temperature (VST)*.

ISO 527-2:1993, *Plastics — Determination of tensile properties — Part 2: Test conditions for moulding and extrusion plastics (incorporating Technical Corrigendum 1:1994)*.

ISO 2808:1997, *Paints and varnishes — Determination of film thickness*.

ISO 4624:—¹⁾, *Paints and varnishes — Pull-off test for adhesion.*

ISO 6506-1:1999, *Metallic materials — Brinell hardness test — Part 1: Test method.*

ISO 6892:1998, *Metallic materials — Tensile testing at ambient temperature.*

ISO 7225, *Gas cylinders — Precautionary labels.*

ISO 7866:1999, *Gas cylinders — Refillable seamless aluminium alloy gas cylinders — Design, construction and testing.*

ISO 9227:1990, *Corrosion tests in artificial atmospheres — Salt spray tests.*

ISO 9712:1999, *Non-destructive testing — Qualification and certification of personnel.*

ISO 9809-1:1999, *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 9809-2:2000, *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:—²⁾, *Gas cylinders — Refillable seamless steel gas cylinders — Design, construction and testing — Part 3: Normalized steel cylinders.*

ISO 14130:1997, *Fibre-reinforced plastic composites — Determination of apparent interlaminar shear strength by short-beam method.*

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

ASTM D1308-87(1998), *Standard Test Method for Effect of Household Chemicals on Clear and Pigmented Organic Finishes.*

ASTM D2794-93(1999)e1, *Standard Test Method for Resistance of Organic Coatings to the Effects of Rapid Deformation (Impact).*

ASTM D3170-87(1996)e1, *Standard Test Method for Chipping Resistance of Coatings.*

ASTM D3418-99, *Standard Test Method for Transition Temperatures of Polymers by Differential Scanning Calorimetry.*

ASTM G53-93³⁾, *Standard Practice for Operating Light and Water-Exposure Apparatus (Fluorescent UV-Condensation Type) for Exposure of Nonmetallic Materials.*

NACE TM0177-96⁴⁾, *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 International Standard the following terms and definitions shall apply:

1) To be published. (Revision of ISO 4624:1978)

2) To be published

3) To be discontinued in 2000 and replaced by G154.

4) NACE standards are available from NACE International, PO Box 218340, Houston, Texas 77218-8340, U.S.A.

3.1**authorized inspection authority**

competent inspection authority, approved or recognized by the regulatory authority of the user country, for the supervision of construction and testing of cylinders

3.2**auto-frettage**

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

NOTE This results in the liner having compressive stresses and the fibres having tensile stresses at zero internal pressure.

3.3**auto-frettage pressure**

pressure within the over-wrapped cylinder at which the required distribution of stresses between the liner and the over-wrap 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**

⟨of 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, process of manufacture, equipment for manufacture and heat treatment, and conditions of time, temperature and atmosphere during heat treatment

3.6**batch**

⟨of 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

NOTE Composite cylinders using non-metallic liners are referred to as all-composite cylinders.

3.9**controlled tension winding**

process used in manufacturing hoop-wrapped composite cylinders with metal liners by which compressive stresses in the liner and tensile stresses in the over-wrap at zero internal pressure are obtained by winding the reinforcing filaments under significant high tension

3.10**filling pressure**

pressure to which a cylinder is filled

3.11

finished cylinders

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

3.12

fully-wrapped cylinder

cylinder with an over-wrap having a filament-wound reinforcement both in the circumferential and axial direction of the cylinder

3.13

gas temperature

temperature of gas in a cylinder

3.14

hoop-wrapped cylinder

cylinder with an over-wrap having a filament-wound reinforcement in a substantially circumferential pattern over the cylindrical portion of the liner so that the filament does not carry any significant load in a direction parallel to the cylinder longitudinal axis

3.15

liner

container that is used as a gas-tight, inner shell, on which reinforcing fibres are filament-wound to reach the necessary strength

NOTE Two types of liner are described in this International Standard – metallic liners that are designed to share the load with the reinforcement, and non-metallic liners that do not carry any part of the load.

3.16

manufacturer

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

3.18

over-wrap

reinforcement system of filament and resin applied over the liner

3.19

prestress

process of applying auto-frettage or controlled tension winding

3.20

service life

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

3.21

settled pressure

gas pressure when a given settled temperature is reached

3.22

settled temperature

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

3.23

test pressure

required pressure applied during a pressure test

3.24

working pressure

settled pressure of 200 bar 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 Use of cylinders

The service conditions specified are also intended to provide information on how cylinders manufactured in accordance with this International Standard may safely be used; this information is intended for

- a) manufacturers of cylinders;
- b) owners of cylinders;
- c) designers or contractors responsible for the installation of cylinders;
- d) designers or owners of equipment used to refuel vehicle cylinders;
- e) suppliers of natural gas;
- f) regulatory authorities who have jurisdiction over cylinder use.

4.1.3 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.

For metal and metal-lined cylinders, the service life shall be based upon the rate of fatigue crack growth. The ultrasonic inspection, or equivalent, of each cylinder or liner shall ensure the absence of flaws which exceed the maximum allowable size. This approach permits the optimized design and manufacture of light weight cylinders for natural gas vehicle service.

For all-composite cylinders with non-metallic non-load bearing liners the service life shall be demonstrated by appropriate design methods, design qualification testing and manufacturing controls.

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 250 bar working pressure system will require pressures to be multiplied by 1,25.

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

- a) a pressure that would settle to 200 bar at a settled temperature of 15 °C;
- b) the maximum 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 a settled pressure of 200 bar at a settled gas temperature of 15 °C for up to 1 000 times per year of service.

4.4 Temperature range

4.4.1 Gas temperature

Cylinders shall be designed to be suitable for the following gas temperature limits:

- a) the settled temperature of gas in cylinders, which may vary from a low of – 40 °C to a high of + 65 °C.
- b) the developed gas temperatures during filling and discharge, which may vary beyond these limits.

4.4.2 Cylinder temperatures

Cylinders shall be designed to be suitable for the following material temperature limits:

- a) the temperature of the cylinder materials may vary from – 40 °C to + 82 °C.
- b) temperatures over + 65 °C shall be sufficiently local, or of short enough duration, that the temperature of gas in the cylinder never exceeds + 65 °C, except under the conditions of 4.4.1 b).

4.5 Gas composition

4.5.1 General

Cylinders shall be designed to tolerate being filled with natural gas meeting the specification either of dry gas or wet gas as follows. Methanol and/or glycol shall not be deliberately added to the natural gas.

4.5.2 Dry gas

Water vapour shall be limited to less than 32 mg/m³ (i.e. a pressure dewpoint of – 9 °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

This is gas that has a higher water content than that of dry gas.

Constituent maximum limits shall be:

Hydrogen sulfide and other soluble sulfides	23 mg/m ³
Oxygen	1 % (volume fraction)

Carbon dioxide	4 % (volume fraction)
Hydrogen	0,1 % (volume fraction)

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 the following, consistent with installation being carried out in accordance with the instructions to be provided with the cylinder:

- 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) ultra-violet 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 Approval and certification

5.1 Inspection and testing

Evaluation of conformity is required to be performed in accordance with the relevant regulations of the country(ies) where the cylinders are used.

In order to ensure that the cylinders are in compliance with this International Standard they shall be subject to design approval in accordance with 5.2, and inspection and testing in accordance with either clause 6, 7, 8 or 9 as appropriate to the construction. This shall be carried out by an authorized inspection authority (hereafter referred to as "the Inspector") recognized in the countries of use. The Inspector shall be competent for inspection of cylinders.

Test procedures are detailed in annex A and annex B. An example of acceptable approval and certification procedures is included in annex C.

5.2 Type approval procedure

5.2.1 General

Type approval consists of 2 parts:

- a) design approval, comprising submission of information by the manufacturer to the Inspector, as detailed in 5.2.2.
- 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 6.5, 7.5, 8.5 or 9.5, 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.

5.2.2 Design approval

Cylinder designs shall be approved by the Inspector. The following information shall be submitted by the manufacturer with a request to the Inspector for approval:

- a) statement of service, in accordance with 5.2.3;
- b) design data, in accordance with 5.2.4;
- c) manufacturing data, in accordance with 5.2.5;
- d) quality system, in accordance with 5.2.6;
- e) fracture performance and NDE defect size, in accordance with 5.2.7;
- f) specification sheet, in accordance with 5.2.8;
- g) additional supporting data, in accordance with 5.2.9.

5.2.3 Statement of service

The purpose of this 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) a specification for the minimum in-service test and/or 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.

5.2.4 Design data

5.2.4.1 Drawings

Drawings shall show at least the following:

- a) title, 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 dimensions complete with tolerances, including details of end closure shapes with minimum thicknesses and of openings;
- d) mass, complete with tolerance, of cylinders;
- e) material specifications, complete with minimum mechanical and chemical properties or tolerance ranges and, for metal cylinders or metal liners, the specified hardness range;

- f) other data such as, autofrettage pressure range, minimum test pressure, details of the fire protection system and of any exterior protective coating.

5.2.4.2 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.

5.2.4.3 Material property data

A detailed 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.

5.2.4.4 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.

5.2.5 Manufacturing data

Details of all fabrication processes, non-destructive examinations, production tests and batch tests shall be provided.

The tolerances for all production processes such as heat treatment, end forming, resin-mix ratio, filament tension and speed for controlled tension winding, curing times and temperatures, and auto-frettage procedures shall be specified.

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

5.2.6 Quality control programme

The manufacturer shall specify methods and procedures in accordance with a quality assurance system acceptable to the Inspector and that will comply with any relevant regulations of the country(ies) where the cylinders are to be used.

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

The manufacturer shall specify the maximum defect size for non-destructive examination which will ensure leak before break (LBB) fracture performance and will prevent failure of the cylinder during its service life due to fatigue, or failure of the cylinder by rupture.

The maximum defect size shall be established by a method suitable to the design, an example of a suitable method is given in annex D.

5.2.8 Specification sheet

A summary of the documents providing the information required in 5.2.2 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.

5.2.9 Additional supporting data

Additional data which would support the application, such as the service history of material proposed for use, or the use of a particular cylinder design in other service conditions, shall be provided where applicable.

5.3 Type approval certificate

If the results of the design approval according to 5.2 and the prototype testing according to 6.5, 7.5, 8.5 or 9.5, as appropriate to the particular cylinder design, are satisfactory, the Inspector shall issue a test type approval certificate. An example of a type approval certificate is given in the annex E.

6 Requirements for type CNG-1 metal cylinders

6.1 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 are capable of consistently passing the materials, design qualification, production and batch tests specified in this International Standard.

The design shall ensure a "leakage-before-break" failure mode under feasible degradation of pressure parts during normal service. If leakage of the metal cylinder occurs, it shall be only by the growth of a fatigue crack.

6.2 Materials

6.2.1 General requirements

Materials used shall be suitable for the service conditions specified in clause 4. The design shall not have incompatible materials in contact.

6.2.2 Controls on chemical composition

6.2.2.1 Steel

Steels shall be aluminium- and/or silicon-killed and produced to predominantly fine grain practice.

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 shown in Table 1.

Table 1 — Maximum sulfur and phosphorus limits

Tensile strength		< 950 MPa	≥ 950 MPa
Level of	sulfur	0,020 %	0,010 %
	phosphorus	0,020 %	0,020 %
	sulfur + phosphorus	0,030 %	0,025 %

6.2.2.2 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 Aluminum Association Inc⁵⁾ entitled *Registration Record of International Alloy Designations and Chemical Composition Limits for Wrought Aluminum and Wrought Aluminum Alloys*.

6.3 Design Requirements

6.3.1 Test pressure

The minimum test pressure used in manufacture shall be 300 bar (1,5 times working pressure).

6.3.2 Burst pressure

The minimum actual burst pressure shall be not less than 450 bar.

6.3.3 Stress analysis

The stresses in the cylinder shall be calculated for 200 bar, test pressure and design burst pressure. The calculations shall use suitable analysis to establish stress distributions to justify the minimum design wall thicknesses.

6.3.4 Maximum defect size

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

The allowable defect size for NDE shall be determined by an appropriate method, e.g. as described in annex D.

6.3.5 Openings

Openings are permitted in heads only. The centre line of openings shall coincide with the longitudinal axis of the cylinder.

6.3.6 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 be approved to a standard acceptable to the Inspector in the country of use.

6.3.7 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.

5) Aluminum Association Inc., 900 19th Street N.W., Washington D.C., 20006-2168, U.S.A.

6.4 Construction and workmanship

6.4.1 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 which have been closed by forming shall be NDE inspected or equivalent.

Metal shall not be added in the process of closure at the ends.

6.4.2 Heat treatment

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

6.4.3 Neck threads

Threads shall be clean cut, even, without surface discontinuities, to gauge and comply with International Standards acceptable to the Inspector.

6.4.4 Exterior environmental protection

The exterior of cylinders shall meet the requirements of the acid environment test of A.14. Exterior protection may be provided by using any of the following:

- 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, the requirements of A.9 shall be met.
- c) a covering impervious to the chemicals listed in A.14.

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.

Manufacturers are advised that an environmental performance test that evaluates the suitability of coating systems is provided in annex F.

6.5 Prototype testing procedure

6.5.1 General requirements

Prototype testing shall be conducted on each new design, on finished cylinders which are representative of normal production and complete with identification marks. The test cylinders shall be selected and the prototype tests detailed in 6.5.2 witnessed by the Inspector. If more cylinders are subjected to the tests than are required by this International Standard, all results shall be documented.

6.5.2 Prototype tests

6.5.2.1 Tests required

In the course of the type approval, the Inspector shall select the necessary cylinders for testing and witness the following tests:

- the tests specified in 6.5.2.2 or 6.5.2.3 (material tests) on 1 cylinder;
- the test specified in 6.5.2.4 (hydrostatic pressure burst test) on 3 cylinders;
- the test specified in 6.5.2.5 (ambient temperature pressure cycling test) on 2 cylinders;
- the test specified in 6.5.2.6 (LBB test) on 3 cylinders;
- the test specified in 6.5.2.7 (bonfire test) on 1 or 2 cylinders as appropriate;
- the test specified in 6.5.2.8 (penetration test) on 1 cylinder.

6.5.2.2 Material tests for steel cylinders

Material tests shall be carried out on steel cylinders as follows:

a) Tensile test

The material properties of the steel in the finished cylinder shall be determined in accordance with A.1 and shall meet the requirements listed therein.

b) Impact test

The impact properties of the steel in the finished cylinder shall be determined in accordance with A.2 and shall meet the requirement listed therein.

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 be subjected to a sulfide stress cracking resistance test in accordance with A.3 and meet the requirements listed therein.

6.5.2.3 Material tests for aluminium alloy cylinders

Material tests shall be carried out on aluminium alloy cylinders as follows:

a) Tensile test

The material properties of the aluminium alloy in the finished cylinder shall be determined in accordance with A.1 and shall meet the requirements listed therein.

b) Corrosion tests

Aluminium alloys shall meet the requirements of the corrosion tests carried out in accordance with A.4.

c) Sustained load cracking tests

Aluminium alloys shall meet the requirements of the sustained load cracking tests carried out in accordance with A.5.

6.5.2.4 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 450 bar.

6.5.2.5 Ambient temperature pressure cycling test

Two cylinders shall be pressure cycled at ambient temperature in accordance with A.13 to failure, or to a minimum of 45 000 cycles. The cylinders shall not fail before reaching the specified service life in years multiplied by 1 000 cycles. Cylinders exceeding 1 000 cycles multiplied by the specified service life in years shall fail by leakage and not by rupture. Cylinders which do not fail within 45 000 cycles shall be destroyed either by continuing the cycling until failure occurs, or by hydrostatically pressurizing to burst. The number of cycles to failure and the location of the failure initiation shall be recorded.

6.5.2.6 Leak-before-break (LBB) test

The LBB test shall be carried out in accordance with A.6 and shall meet the requirements listed therein.

6.5.2.7 Bonfire test

One or two cylinders as appropriate shall be tested in accordance with A.15 and meet the requirements listed therein.

6.5.2.8 Penetration test

One cylinder shall be tested in accordance with A.16 and meet the requirements listed therein.

6.5.3 Change of design

A design change is any change in the selection of structural materials or dimensional change not attributable to normal manufacturing tolerances.

Minor design changes shall be permitted to 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 CNG-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	X	X	X	X	X
Diameter change $\leq 20\%$	X	X	—	—	—
Diameter change $> 20\%$	X	X	X	X	X
Length change $\leq 50\%$	X	—	—	X ^a	—
Length change $> 50\%$	X	X	—	X ^a	—
Working pressure change $\leq 20\%$ ^b	X	X	—	—	—
Dome shape	X	X	—	—	—
Opening size	X	X	—	—	—
Change in manufacturing process	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.

6.6 Batch tests

6.6.1 General requirements

Batch testing shall be conducted on finished cylinders which are representative of normal production and are complete with 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 witness 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 periodic pressure cycling test, provided that during their type approval testing the cylinders withstand pressure cycling without failure for a minimum of 15 000 pressure cycles from not more than 20 bar to not less than 300 bar (in accordance with the test procedure given in A.6), or for a minimum of 30 000 pressure cycles from not more than 20 bar to not less than 260 bar (in accordance with the test procedure given in A.13).

6.6.2 Test programme

6.6.2.1 The following 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 5.2.4.1);
 - 2) one tensile test in accordance with A.1; the test results shall satisfy the requirements of the design (see 5.2.4.1);
 - 3) for steel cylinders, three impact tests in accordance with A.2; the test results shall satisfy the requirements specified in A.2;
 - 4) 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 6.9.

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

- 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 6.5.3), none of the pressure cycled cylinders in a) above leaks or ruptures in less than 1 500 cycles multiplied by the specified life in years (minimum 22 500 cycles) then the pressure cycle test may be reduced to one cylinder from every 5 batches of production;
- c) if on 10 sequential production batches of a design family, none of the pressure cycled cylinders in a) above leaks or ruptures in less than 2 000 cycles multiplied by the specified service life in years (minimum 30 000 cycles) then the pressure cycle test may be reduced to one cylinder from every 10 batches of production;

- d) should more than 3 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 b) or c) above;
- e) should any reduced frequency pressure cycle test cylinder in b) or c) above fail to meet the required number of pressure cycles (minimum 22 500 or 30 000 pressure cycles, respectively), then it shall be necessary to repeat the batch pressure cycle test frequency in a) for a minimum of 10 production batches in order to re-establish the reduced frequency of batch pressure cycle testing in b) or c) above.

Should any cylinder in a), b) or c) above fail to meet the minimum cycle life requirement of 1 000 cycles multiplied by the specified service life in years (minimum 15 000 cycles), then the cause of failure shall be determined and corrected following the procedures in 6.9. 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, then the batch shall be rejected.

6.7 Tests on every cylinder

Production examinations and tests shall be carried out on all cylinders produced in a batch. Non-destructive examinations shall be carried out in accordance with a standard acceptable to the Inspector.

Each cylinder shall be examined during manufacture and after completion as follows:

- 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 6.3.4. 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 compliance with 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 markings;
- 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 hydraulic test of finished cylinders in accordance with A.11. If Option 1 is chosen, the manufacturer shall establish the appropriate limit of permanent volumetric 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.

6.8 Batch acceptance certificate

If the results of batch testing according to 6.6 and 6.7 are satisfactory, the manufacturer and the Inspector shall sign an acceptance certificate. An example of an acceptance certificate (referred to as a "Report of Manufacture and Certificate of Conformance") is given in annex E.

6.9 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 as follows to the satisfaction of the Inspector:

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

- 1) If the failure is considered to be due to the heat treatment applied, the manufacturer may subject all the cylinders implicated by the failure to a further heat treatment 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; however if the failure occurs sporadically in a test applied to every cylinder, then only those cylinders which fail the test shall require re-heat treatment and 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.
- 2) 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.

7 Requirements for type CNG-2 hoop-wrapped 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 cylinders being capable of consistently passing 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 linearly superimposed. Due to different techniques of manufacture, this International Standard does not give a definite method for design.

The design shall ensure a “leakage-before-break” failure mode under feasible degradation of pressure parts during normal service. If leakage of the metal liner occurs, it shall be only by the growth of a fatigue crack.

7.2 Materials

7.2.1 General requirements

Materials used shall be suitable for the service conditions specified in clause 4. The design shall ensure that incompatible materials are not in contact.

7.2.2 Controls on chemical composition

7.2.2.1 Steel

Steels shall be aluminium- and/or silicon-killed and produced to predominantly fine grain practice. 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 shown in Table 3.

Table 3 — Maximum sulfur and phosphorus limits

Tensile strength		< 950 MPa	≥ 950 MPa
Level of	sulfur	0,020 %	0,010 %
	phosphorus	0,020 %	0,020 %
	sulfur + phosphorus	0,030 %	0,025 %

7.2.2.2 Aluminium

Aluminium alloys may be used to produce cylinders provided 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 Aluminum Association Inc entitled *Registration Record of International Alloy Designations and Chemical Composition Limits for Wrought Aluminum and Wrought Aluminum Alloys*.

7.2.3 Composite materials

7.2.3.1 Resins

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

The glass transition temperature of the resin material shall be determined in accordance with ASTM D3418-99.

7.2.3.2 Fibres

Structural reinforcing filament material types shall be glass fibre, aramid fibre or carbon fibre. If carbon fibre reinforcement is used the design shall incorporate means to prevent galvanic corrosion of the metallic components of the cylinder.

The manufacturer shall keep on file the published specifications for composite materials, the material manufacturer's recommendations for storage, conditions and shelf life and the material manufacturer's certification that each shipment conforms to said specification requirements. The fibre manufacturer shall certify that the fibre material properties conform to the manufacturer's specifications for the product.

7.3 Design requirements

7.3.1 Test pressure

The minimum test pressure used in manufacture shall be 300 bar (1,5 times working pressure).

7.3.2 Burst pressures and fibre stress ratios

The metal liner shall have a minimum actual burst pressure of 260 bar.

The minimum actual burst pressure shall be not less than the values given in Table 4. The composite over-wrap shall be designed for high reliability under sustained loading and cyclic loading. This reliability shall be achieved by meeting or exceeding the composite reinforcement stress ratio values given in Table 4. Stress ratio is defined as the stress in the fibre at the specified minimum burst pressure divided by the stress in the fibre at working pressure. The burst ratio is defined as the actual burst pressure of the cylinder divided by the working pressure.

The stress ratio calculations shall include

- a) an analysis method with capability for non-linear materials (special purpose computer program or finite element analysis program);
- b) correct modelling of the elastic-plastic stress-strain curve for a known liner material;
- c) correct modelling of the mechanical properties of composite materials;
- d) calculations at autofrettage pressure, zero pressure after autofrettage, working pressure, and minimum burst pressure;
- e) account for the prestresses from winding tension;
- f) the minimum burst pressure, chosen such that the calculated stress at minimum burst pressure divided by the calculated stress at working pressure meets the stress ratio requirements for the fibre used;
- g) consideration of the load share between the different fibres based on the different elastic moduli of the fibres when analysing cylinders with hybrid reinforcement (two or more different fibres). The stress ratio requirements for each individual fibre type shall be in accordance with the values given in Table 4.

Verification of the stress ratios may also be performed using strain gauges. An acceptable method is outlined in annex G.

Table 4 — Minimum actual burst values and stress ratios for type CNG-2 cylinders

Fibre Type	Stress Ratio	Burst Pressure bar
Glass	2,75	500 ^a
Aramid	2,35	470
Carbon	2,35	470
Hybrid	b	

^a Minimum actual burst pressure. In addition, calculations shall be performed in accordance with 7.3.2 to confirm that the minimum stress ratio requirements are also met.

^b Stress ratios and burst pressures shall be calculated in accordance with 7.3.2.

7.3.3 Stress analysis

The stresses in the composite and in the liner after prestress shall be calculated for 0 bar, 200 bar, test pressure and design burst pressure. The calculations shall use suitable analysis techniques taking into account non-linear material behaviour of the liner when establishing stress distributions.

For designs using auto-frettage to provide prestress, the limits within which the auto-frettage pressure shall fall shall be calculated and specified. For designs using controlled tension winding to provide prestress, the temperature at which it is performed, the tension required in each layer of composite and the consequent prestress in the liner shall be calculated.

7.3.4 Maximum defect size

The maximum defect size at any location in the metal liner such that the cylinder meet pressure cycling and LBB requirements shall be specified. The NDE method shall be capable of detecting the maximum defect size allowed.

The allowable defect size for NDE shall be determined by an appropriate method, e.g. as described in annex D.

7.3.5 Openings

Openings are permitted in heads only. 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 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 be approved to a standard acceptable to the Inspector in the country of use.

7.4 Construction and workmanship

7.4.1 General

The composite cylinder shall be manufactured from a liner over-wrapped with continuous filament windings. Fibre winding operations shall be computer or mechanically controlled. The fibres shall be applied under controlled tension during winding. After winding is complete, thermosetting resins shall be cured by heating, using a predetermined and controlled time-temperature profile.

7.4.2 Liner

The manufacture of a metallic liner shall meet the requirements given in 7.2, 7.3.2 and either 7.5.2.2 or 7.5.2.3 for the appropriate type of liner construction.

7.4.3 Neck threads

Threads shall be clean cut, even, without surface discontinuities, to gauge and comply with International Standards acceptable to the Inspector.

7.4.4 Over-wrap

7.4.4.1 Fibre winding

The cylinders shall be manufactured by a fibre winding technique. During winding the significant variables shall be monitored within specified tolerances and documented in a winding record. These variables can include but are not limited to:

- a) fibre type including sizing;
- b) manner of impregnation;
- c) winding tension;
- d) winding speed;
- e) number of rovings;
- f) band width;
- g) type of resin and composition;
- h) temperature of the resin;

- i) temperature of the liner;
- j) winding angle.

7.4.4.2 Curing of thermosetting resins

If a thermosetting resin is used, the resin shall be cured after filament winding. During the curing, the curing cycle (i.e. the time-temperature history) shall be documented.

The maximum curing time and temperature for cylinders with aluminium alloy liners shall be below the time and temperature which adversely affect metal properties.

7.4.4.3 Auto-frettagage

Auto-frettagage, if used, shall be carried out before the hydrostatic pressure test. The auto-frettagage pressure shall be within the limits established in 7.3.3, and the manufacturer shall establish the method of verifying the appropriate pressure.

7.4.5 Exterior environmental protection

The exterior of cylinders shall meet the requirements of the acid environment test described in A.14. Exterior protection may be provided by using any of the following:

- a) a surface finish giving adequate protection (e.g. metal sprayed on to aluminium, anodizing); or
- b) the use of a suitable fibre and matrix material (e.g. carbon fibre in resin); or
- c) a protective coating (e.g. organic coating, paint); if exterior coating is part of the design, the requirements of A.9 shall be met; or
- d) a covering impervious to the chemicals listed in A.14.

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 to ensure the continued integrity of the cylinder.

Manufacturers are advised that an environmental performance test that evaluates the suitability of coating systems is provided in annex F.

7.5 Prototype testing procedure

7.5.1 General requirements

Prototype testing shall be conducted on each new design, on finished cylinders which are representative of normal production and complete with identification marks. The test cylinders or liners shall be selected and the prototype tests detailed in 7.5.2 witnessed by the Inspector. If more cylinders or liners 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

In the course of the type approval, the Inspector shall select the necessary cylinders or liners for testing and witness the following tests:

- the tests specified in 7.5.2.2 or 7.5.2.3 (material tests), as appropriate, on 1 liner;

- the test specified in 7.5.2.4 (hydrostatic pressure burst test) on 1 liner and 3 cylinders;
- the test specified in 7.5.2.5 (ambient temperature pressure cycling test) on 2 cylinders;
- the test specified in 7.5.2.6 (LBB test) on 3 cylinders;
- the test specified in 7.5.2.7 (bonfire test) on 1 or 2 cylinders as appropriate;
- the test specified in 7.5.2.8 (penetration test) on 1 cylinder;
- the test specified in 7.5.2.9 (acid environment test) on 1 cylinder;
- the test specified in 7.5.2.10 (flaw tolerance test) on 1 cylinder;
- the test specified in 7.5.2.11 (high temperature creep test), where appropriate, on 1 cylinder;
- the test specified in 7.5.2.12 (accelerated stress rupture test), on 1 cylinder;
- the test specified in 7.5.2.13 (extreme temperature pressure cycling test) on 1 cylinder;
- the test specified in 7.5.2.14 (resin shear strength) on 1 sample coupon representative of the composite overwrap.

7.5.2.2 Material tests for steel liners

Material tests shall be carried out on steel liners as follows:

a) Tensile test

The material properties of the steel in the finished liner shall be determined in accordance with A.1 and shall meet the requirements therein.

b) Impact test

The impact properties of the steel in the finished liner shall be determined in accordance with A.2 and shall meet the requirements therein.

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 be subjected to a sulfide stress cracking resistance test in accordance with A.3 and meet the requirements therein.

7.5.2.3 Material tests for aluminium alloy liners

Material tests shall be carried out on aluminium alloy liners as follows:

a) Tensile test

The material properties of the aluminium alloy in the finished cylinder shall be determined in accordance with A.1 and shall meet the requirements therein.

b) Corrosion tests

Aluminium alloys shall meet the requirements of the corrosion tests carried out in accordance with A.4.

c) Sustained load cracking tests

Aluminium alloys shall meet the requirements of the sustained load cracking tests carried out in accordance with A.5.

7.5.2.4 Hydrostatic pressure burst test

- a) One liner shall be hydrostatically pressurized to failure in accordance with A.12. The burst pressure shall exceed the minimum burst pressure specified for the liner design.
- b) Three cylinders shall be hydrostatically pressurized to failure in accordance with A.12. The cylinder burst pressures shall exceed the specified minimum burst pressure calculated by the stress analysis for the design, in accordance with Table 4, and in no case be less than the value necessary to meet the stress ratio requirements of 7.3.2.

7.5.2.5 Ambient temperature pressure cycling test

Two cylinders shall be pressure cycled to failure at ambient temperature in accordance with A.13, or to a minimum of 45 000 cycles. The cylinders shall not fail before reaching the specified service life in years multiplied by 1 000 cycles. Cylinders exceeding 1 000 cycles multiplied by the specified service life in years shall fail by leakage and not by rupture. Cylinders which do not fail within 45 000 cycles shall be destroyed either by continuing the cycling until failure occurs, or by hydrostatically pressurizing to burst. Cylinders exceeding 45 000 cycles are permitted to fail by rupture. The number of cycles to failure and the location of the failure initiation shall be recorded.

7.5.2.6 Leak-before-break (LBB) test

The LBB test shall be carried out in accordance with A.6 and shall meet the requirements therein.

7.5.2.7 Bonfire test

One or two cylinders as appropriate shall be tested in accordance with A.15 and meet the requirements therein.

7.5.2.8 Penetration test

One cylinder shall be tested in accordance with A.16 and meet the requirements therein.

7.5.2.9 Acid environment test

One cylinder shall be tested in accordance with A.14 and meet the requirements therein.

An optional environmental test is included in annex F.

7.5.2.10 Flaw tolerance tests

One cylinder shall be tested in accordance with A.17 and meet the requirements therein.

7.5.2.11 High temperature creep test

In designs where the glass transition temperature of the resin does not exceed 102 °C, one cylinder shall be tested in accordance with A.18 and meet the requirements therein.

7.5.2.12 Accelerated stress rupture test

One cylinder shall be tested in accordance with A.19 and meet the requirements therein.

7.5.2.13 Extreme temperature pressure cycling test

One cylinder shall be tested in accordance with A.7 and meet the requirements therein.

7.5.2.14 Resin shear strength

Resin materials shall be tested in accordance with A.26, and meet the requirements therein.

7.5.3 Change of design

A design change is any change in the selection of structural materials or dimensional change not attributable to normal manufacturing tolerances.

Minor design changes shall be permitted to be qualified through a reduced test programme. Changes of design specified in Table 5 shall require only the prototype testing as specified in the table.

Table 5 — Change of design for type CNG-2 cylinders

Design change	Type of test							
	Hydrostatic burst	Pressure cycling at ambient temperature	Bonfire	Pene-tration	Environ-mental	Flaw tolerance	High temperature creep	Stress rupture
	Clause							
	A.12	A.13	A.15	A.16	A.14	A.17	A.18	A.19
Fibre manufacturer	X	X	—	—	—	—	X	X
Metallic liner material	X	X	X	X	X	X	X	X
Fibre material	X	X	X	X	X	X	X	X
Resin material	—	—	—	X	X	X	X	X
Diameter change $\leq 20\%$	X	X	—	—	—	—	—	—
Diameter change $> 20\%$	X	X	X	X	—	X	—	—
Length change $\leq 50\%$	X		X ^a	—	—		—	—
Length change $> 50\%$	X	X	X ^a	—	—	—	—	—
Working pressure change $\leq 20\%$ ^b	X	X	—	—	—	—	—	—
Dome shape	X	X	—	—	—	—	—	—
Opening size	X	X	—	—	—	—	—	—
Coating change			—	—	X	—	—	—
Change in manufacturing process	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.								

7.6 Batch tests

7.6.1 General requirements

Batch testing shall be conducted on finished cylinders which are representative of normal production and are complete with identification marks. The cylinders and liners 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. Where defects are detected in over-wrapping before any auto-fretting or hydrostatic pressure testing, the over-wrapping may be completely removed and replaced.

7.6.2 Required tests

7.6.2.1 At least the following tests shall be carried out on each batch of cylinders:

a) on one cylinder:

— one hydrostatic pressure burst test in accordance with A.12.

If the burst pressure is less than the minimum calculated burst pressure, the procedures specified in 7.9 shall be followed.

b) On a further cylinder, or liner, or heat treated witness sample representative of a finished cylinder:

- 1) a check of the critical dimensions against the design (see 5.2.4.1);
- 2) one tensile test in accordance with A.1; the test results shall satisfy the requirements of the design (see 5.2.4.1);
- 3) for steel liners, three impact tests in accordance with A.2; the test results shall satisfy the requirements specified in A.2;
- 4) 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 similarly defectively coated cylinders. The coating on all defectively coated cylinders may be stripped using a method that does not affect the integrity of the composite wrapping then recoated. The coating batch test shall then be repeated.

All cylinders or liners represented by a batch test which fails to meet the specified requirements shall follow the procedures specified in 7.9

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

- 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 a) above leaks or ruptures in less than 1 500 cycles multiplied by the specified life in years (minimum 22 500 cycles) then the pressure cycle test may be reduced to one cylinder from every 5 batches of production;
- c) if on 10 sequential production batches of a design family, none of the pressure cycled cylinders in a) above leaks or ruptures in less than 2 000 cycles multiplied by the specified service life in years (minimum 30 000 cycles) then the pressure cycle test can be reduced to one cylinder from every 10 batches of production;
- d) should more than 3 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 b) or c) above;

- e) should any reduced frequency pressure cycle test cylinder in b) or c) above fail to meet the required number of pressure cycles (minimum 22 500 or 30 000 pressure cycles, respectively), then it shall be necessary to repeat the batch pressure cycle test frequency in a) for a minimum of 10 production batches in order to re-establish the reduced frequency of batch pressure cycle testing in b) or c) above.

Should any cylinder in a), b) or c) above fail to meet the minimum cycle life requirement of 1 000 cycles multiplied by the specified service life in years (minimum 15 000 cycles), then the cause of failure shall be determined and corrected in accordance with 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, then the batch shall be rejected.

7.7 Tests on every cylinder

Production examinations and tests shall be carried out as follows on all cylinders produced in a batch. Non-destructive examinations shall be carried out in accordance with a standard acceptable to the Inspector.

Each cylinder shall be examined during manufacture and after completion as follows:

- a) by NDE of metallic liners in accordance with Annex B or demonstrated 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 size allowed;
- b) to verify that the critical dimensions and mass of the completed cylinders and of the liners and overwrapping are within design tolerances;
- c) to verify compliance with 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 markings;
- e) by hardness tests of metallic liners in accordance with A.8 carried out after the final heat treatment. The values thus determined shall be in the range specified for the design;
- f) by hydraulic test of finished cylinders in accordance with A.11, option 1. The manufacturer shall establish the appropriate limit of permanent volumetric expansion for the test pressure used, but in no case shall the permanent expansion exceed 5 % of the total volumetric expansion measured under the test pressure.

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. An example of an acceptance certificate (referred to as a "Report of Manufacture and Certificate of Conformance") is given in annex E.

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 as follows to the satisfaction of the Inspector:

- a) if there is evidence of a fault in carrying out a test, or an error of measurement, a further test shall be performed; if the result of this test is satisfactory, the first test shall be ignored;
- b) If the test has been carried out in a satisfactory manner, the cause of test failure shall be identified.
 - 1) If the failure is considered to be due to the heat treatment applied, the manufacturer may subject all the cylinders implicated by the failure to a further heat treatment, 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; however if the failure occurs sporadically in a test applied to every cylinder, then only those cylinders which fail the test shall require re-heat treatment and re-testing.

- Whenever liners 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.
- 2) If the failure is due to a cause other than the heat treatment applied, 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 CNG-3 fully-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 are capable of consistently passing the materials, design qualification, production and batch tests specified in this International Standard.

During pressurization, this type of cylinder exhibits behaviour in which the displacements of the composite over-wrap and the liner are superimposed. Due to different techniques of manufacture, this International Standard does not give a definite method for design.

The design shall ensure a “leakage-before-break” failure mode under feasible degradation of pressure parts during normal service. If leakage of the metal liner occurs, it shall be only by the growth of a fatigue crack.

8.2 Materials

8.2.1 General requirements

Materials used shall be suitable for the service conditions specified in clause 4. The design shall ensure that incompatible materials are not in contact.

8.2.2 Controls on chemical composition

8.2.2.1 Steel

Steels shall be aluminium- and/or silicon-killed and produced to predominantly fine grain practice. 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 in Table 6.

Table 6 — Maximum sulfur and phosphorus limits

Tensile strength		< 950 Mpa	≥ 950 MPa
Level of	sulfur	0,020 %	0,010 %
	phosphorus	0,020 %	0,020 %
	sulfur + phosphorus	0,030 %	0,025 %

8.2.2.2 Aluminium

Aluminium alloys may be used to produce cylinders provided 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 Aluminum Association Inc entitled 'Registration Record of International Alloy Designations and Chemical Composition Limits for Wrought Aluminum and Wrought Aluminum Alloys'.

8.2.3 Composite materials

8.2.3.1 Resins

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

The glass transition temperature of the resin material shall be determined in accordance with ASTM D3418-99.

8.2.3.2 Fibres

Structural reinforcing filament material types shall be glass fibre, aramid fibre or carbon fibre. If carbon fibre reinforcement is used the design shall incorporate means to prevent galvanic corrosion of metallic components of the cylinder.

The manufacturer shall keep on file the published specifications for composite materials, the material manufacturer's recommendations for storage, conditions and shelf life and the material manufacturer's certification that each shipment conforms to said specification requirements. The fibre manufacturer shall certify that the fibre material properties conform to the manufacturer's specifications for the product.

8.3 Design requirements

8.3.1 Test pressure

The minimum test pressure used in manufacture shall be 300 bar (1,5 times working pressure).

8.3.2 Burst pressures and fibre stress ratios

The minimum actual burst pressure shall not be less than the values given in Table 7. The composite over-wrap shall be designed for high reliability under sustained loading and cyclic loading. This reliability shall be achieved by meeting or exceeding the composite reinforcement stress ratio values given in Table 7. Stress ratio is defined as the stress in the fibre at the specified minimum burst pressure divided by the stress in the fibre at working pressure. The burst ratio is defined as the actual burst pressure of the cylinder divided by the working pressure.

The stress ratio calculations shall include:

- a) an analysis method with capability for non-linear materials (special purpose computer program or finite element analysis program);
- b) correct modelling of the elastic-plastic stress-strain curve for a known liner material;
- c) correct modelling of the mechanical properties of the composite;
- d) calculations at autofrettage pressure, zero pressure after autofrettage, working pressure and minimum burst pressure;
- e) account for the prestresses from winding tension;

- f) the minimum burst pressure, chosen such that the calculated stress at minimum burst pressure divided by the calculated stress at working pressure meets the stress ratio requirements for the fibre used;
- g) consideration of the load share between the different fibres based on the different elastic moduli of the fibres when analysing cylinders with hybrid reinforcement (two or more different fibres). The stress ratio requirements for each individual fibre type shall be in accordance with the values given in Table 7.

Verification of the stress ratios may also be performed using strain gauges. An acceptable method is outlined in annex G.

Table 7 — Minimum actual burst values and stress ratios for type CNG-3 cylinders

Fibre type	Stress Ratio	Burst Pressure bar
Glass	3,65	700 ^a
Aramid	3,10	600
Carbon	2,35	470
Hybrid	b	

^a Minimum actual burst pressure. In addition, calculations shall be performed in accordance with 8.3.2 to confirm that the minimum stress ratio requirements are also met.

^b Stress ratios and burst pressures shall be calculated in accordance with 8.3.2.

8.3.3 Stress analysis

A stress analysis shall be performed to justify the minimum design wall thicknesses. It shall include the determination of the stresses in liners and fibres of composite designs.

The stresses in the tangential and longitudinal direction of the cylinder in the composite and in the liner after prestress shall be calculated for 0 bar, 200 bar, test pressure and design burst pressure. The calculations shall use suitable analysis taking into account non-linear material behaviour of the liner when establishing stress distributions.

The limits within which the autofrettage pressure shall fall shall be calculated.

8.3.4 Maximum defect size

The maximum defect size at any location in the metal liner such that the cylinder meet pressure cycling and LBB requirements shall be specified. The NDE method shall be capable of detecting the maximum defect size allowed.

The allowable defect size for NDE shall be determined by an appropriate method, e.g. as per Annex D.

8.3.5 Openings

Openings are permitted in heads only. The centre line of openings shall coincide with the longitudinal axis of the cylinder.

8.3.6 Fire protection

The cylinder design shall be protected with pressure relief devices. The cylinder, its materials, pressure relief devices 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 to optimize safety considerations.

Pressure relief devices shall be approved to a standard acceptable to the Inspector in the country of use.

8.4 Construction and workmanship

8.4.1 General

The composite cylinder shall be manufactured from a liner over-wrapped with continuous filament windings. Fibre winding operations shall be computer or mechanically controlled. The fibres shall be applied under controlled tension during winding. After winding is complete, thermosetting resins shall be cured by heating, using a predetermined and controlled time-temperature profile.

8.4.2 Liner

The manufacture of a metallic liner shall meet the requirements specified in 8.2, 8.3.2 and either 8.5.2.2 or 8.5.2.3 for the appropriate type of liner construction.

The compressive stress in the liner at zero pressure and 15 °C shall not cause the liner to buckle or crease.

8.4.3 Neck threads

Threads shall be clean cut, even, without surface discontinuities, to gauge and comply with International Standards acceptable to the Inspector.

8.4.4 Over-wrap

8.4.4.1 Fibre winding

The cylinders shall be manufactured by a fibre winding technique. During winding the significant variables shall be monitored within specified tolerances and documented in a winding record. These variables can include but are not limited to:

- a) fibre type including sizing;
- b) manner of impregnation;
- c) winding tension;
- d) winding speed;
- e) number of rovings;
- f) band width;
- g) type of resin and composition;
- h) temperature of the resin;
- i) temperature of the liner;
- j) winding angle.

8.4.4.2 Curing of thermosetting resins

If a thermosetting resin is used, the resin shall be cured after filament winding. During curing, the curing cycle (i.e. the time-temperature history) shall be documented.

The maximum curing time and temperature for cylinders with aluminium alloy liners shall be below the time and temperature which adversely affect metal properties.

8.4.4.3 Auto-fretting

Auto-fretting, if used, shall be carried out before the hydrostatic pressure test. The auto-fretting pressure shall be within the limits established in 8.3.3, and the manufacturer shall establish the method of verifying the appropriate pressure.

8.4.5 Exterior environmental protection

The exterior of cylinders shall meet the requirements of the acid environment test described in A.14. Exterior protection may be provided by using any of the following:

- a) a surface finish giving adequate protection (e.g. metal sprayed on to aluminium, anodizing); or
- b) the use of a suitable fibre and matrix material (e.g. carbon fibre in resin); or
- c) a protective coating (e.g. organic coating, paint); if exterior coating is part of the design, the requirements of A.9 shall be met; or
- d) a covering impervious to the chemicals listed in A.14.

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 to ensure the continued integrity of the cylinder.

Manufacturers are advised that an environmental performance test that evaluates the suitability of coating systems is provided in annex F.

8.5 Prototype testing procedure

8.5.1 General requirements

Prototype testing shall be conducted on each new design, on finished cylinders which are representative of normal production and complete with identification marks. The test cylinders or liners shall be selected and the prototype tests detailed in 8.5.2 witnessed by the Inspector. If more cylinders or liners are subjected to the tests than are required by this International Standard, all results shall be documented.

8.5.2 Prototype tests

8.5.2.1 Tests required

In the course of the type approval, the Inspector shall select the necessary cylinders or liners for testing and witness the following tests:

- the tests specified in 8.5.2.2 or 8.5.2.3 (material tests), as appropriate, on 1 liner;
- the test specified in 8.5.2.4 (hydrostatic pressure burst test) on 3 cylinders;
- the test specified in 8.5.2.5 (ambient temperature pressure cycling test) on 2 cylinders;
- the test specified in 8.5.2.6 (LBB test) on 3 cylinders;
- the test specified in 8.5.2.7 (bonfire test) on 1 or 2 cylinders as appropriate;

- the test specified in 8.5.2.8 (penetration test) on 1 cylinder;
- the test specified in 8.5.2.9 (acid environment test) on 1 cylinder;
- the test specified in 8.5.2.10 (flaw tolerance test) on 1 cylinder;
- the test specified in 8.5.2.11 (high temperature creep test), where appropriate, on 1 cylinder;
- the test specified in 8.5.2.12 (accelerated stress rupture test), on 1 cylinder;
- the test specified in 8.5.2.13 (extreme temperature pressure cycling test) on 1 cylinder;
- the test specified in 8.5.2.14 (resin shear strength) on 1 sample coupon representative of the composite overwrap;
- the test specified in 8.5.2.15 (drop test) on at least 1 cylinder.

8.5.2.2 Material tests for steel liners

Material tests shall be carried out on steel liners as follows:

a) Tensile test

The material properties of the steel in the finished cylinder or liner shall be determined in accordance with A.1 and shall meet the requirements therein.

b) Impact test

The impact properties of the steel in the finished cylinder or liner shall be determined in accordance with A.2 and shall meet the requirements therein.

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 be tested in accordance with A.3 and meet the requirements therein.

8.5.2.3 Material tests for aluminium alloy liners

Material tests shall be carried out on aluminium alloy liners as follows:

a) Tensile test

The material properties of the aluminium alloy in the finished cylinder shall be determined in accordance with A.1 and shall meet the requirements therein.

b) Corrosion tests

Aluminium alloys shall meet the requirements of the corrosion tests carried out in accordance with A.4.

c) Sustained load cracking tests

Aluminium alloys shall meet the requirements of the sustained load cracking tests carried out in accordance with A.5.

8.5.2.4 Hydrostatic pressure burst test

Three cylinders shall be hydrostatically pressurized to failure in accordance with A.12. The cylinder burst pressures shall exceed the specified minimum burst pressure established by the stress analysis for the design, in accordance with Table 7, and in no case be less than the value necessary to meet the stress ratio requirements of 8.3.2.

8.5.2.5 Ambient temperature pressure cycling test

Two cylinders shall be pressure cycle tested to failure at ambient temperature in accordance with A.13, or to a minimum of 45 000 cycles. The cylinders shall not fail before reaching the specified service life in years multiplied by 1 000 cycles. Cylinders exceeding 1 000 cycles multiplied by the specified service life in years shall fail by leakage and not by rupture. Cylinders which do not fail within 45 000 cycles shall be destroyed either by continuing the cycling until failure occurs, or by hydrostatically pressurizing to burst. Cylinders exceeding 45 000 cycles are permitted to fail by rupture. The number of cycles to failure and the location of the failure initiation shall be recorded.

8.5.2.6 Leak-before-break (LBB) test

The LBB test shall be carried out in accordance with A.6 and shall meet the requirements therein.

8.5.2.7 Bonfire test

One or two cylinders as appropriate shall be tested in accordance with A.15 and meet the requirements therein.

8.5.2.8 Penetration test

One cylinder shall be tested in accordance with A.16 and meet the requirements therein.

8.5.2.9 Acid environment test

One cylinder shall be tested in accordance with A.14 and meet the requirements therein.

An optional environmental test is included in annex F.

8.5.2.10 Flaw tolerance tests

One cylinder shall be tested in accordance with A.17 and meet the requirements therein.

8.5.2.11 High temperature creep test

In designs where the glass transition temperature of the resin does not exceed 102 °C, one cylinder shall be tested in accordance with A.18 and meet the requirements therein.

8.5.2.12 Accelerated stress rupture test

One cylinder shall be tested in accordance with A.19 and meet the requirements therein.

8.5.2.13 Extreme temperature pressure cycling test

One cylinder shall be tested in accordance with A.7 and meet the requirements therein.

8.5.2.14 Resin shear strength

Resin materials shall be tested in accordance with A.26 and meet the requirements therein.

8.5.2.15 Drop test

One (or more) finished cylinders shall be drop tested in accordance with A.20 and meet the requirements therein.

8.5.3 Change of design

A design change is any change in the selection of structural materials or dimensional change not attributable to normal manufacturing tolerances.

Minor design changes shall be permitted to be qualified through a reduced test programme. Changes of design specified in Table 8 shall require design qualification testing as specified in the table.

Table 8 — Change of design for type CNG-3 cylinders

Design change	Type of test								
	Hydrostatic burst	Pressure cycling at ambient temperature	Bonfire	Penetration	Environmental	Flaw tolerance	High temperature creep	Stress rupture	Drop
	Clause								
	A.12	A.13	A.15	A.16	A.14	A.17	A.18	A.19	A.20
Fibre manufacturer	X	X	—	—	—	—	X	X	X
Metallic liner material	X	X	X	X	X	X	X	X	X
Fibre material	X	X	X	X	X	X	X	X	X
Resin material	—	—	—	X	X	X	X	X	X
Diameter change $\leq 20\%$	X	X	—	—	—	—	—	—	—
Diameter change $> 20\%$	X	X	X	X	—	X	—	—	X
Length change $\leq 50\%$	X	—	X ^a	—	—	—	—	—	—
Length change $> 50\%$	X	X	X ^a	—	—	—	—	—	X
Working pressure change $\leq 20\%$ ^b	X	X	—	—	—	—	—	—	—
Dome shape	X	X	—	—	—	—	—	—	—
Opening size	X	X	—	—	—	—	—	—	—
Coating change	—	—	—	—	X	—	—	—	—
Change in manufacturing process	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.									

8.6 Batch tests

8.6.1 General requirements

Batch testing shall be conducted on finished cylinders which are representative of normal production and are complete with identification marks. The cylinders and liners 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. Where defects are detected in over-wrapping before any auto-frettagage or hydrostatic pressure testing, the over-wrapping may be completely removed and replaced.

8.6.2 Required tests

8.6.2.1 At least the following tests shall be carried out on each batch of cylinders:

- a) on one cylinder:
 - 1) one hydrostatic pressure burst test in accordance with A.12.
 - If the burst pressure is less than the minimum calculated burst pressure, the procedures specified in 8.9 shall be followed.
- b) on a further cylinder, or liner, or heat treated witness sample representative of a finished cylinder:
 - 1) a check of the critical dimensions against the design (see 5.2.4.1);
 - 2) one tensile test in accordance with A.1; the test results shall satisfy the requirements of the design (see 5.2.4.1);
 - 3) for steel liners, three impact tests in accordance with A.2; the test results shall satisfy the requirements specified in A.2;
 - 4) 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 similarly defectively coated cylinders. The coating on all defectively coated cylinders may be stripped using a method that does not affect the integrity of the composite wrapping then recoated. The coating batch test shall then be repeated.

All cylinders or liners represented by a batch test which fails to meet the requirements specified shall follow the procedures specified in 8.9.

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

- 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 8.5.3), none of the pressure cycled cylinders in a) above leaks or ruptures in less than 1 500 cycles multiplied by the specified life in years (minimum 22 500 cycles) then the pressure cycle test may be reduced to one cylinder from every 5 batches of production;
- c) if on 10 sequential production batches of a design family, none of the pressure cycled cylinders in a) above leaks or ruptures in less than 2 000 cycles multiplied by the specified service life in years (minimum 30 000 cycles) then the pressure cycle test can be reduced to one cylinder from every 10 batches of production;
- d) should more than 3 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 b) or c) above;
- e) should any reduced frequency pressure cycle test cylinder in b) or c) above fail to meet the required number of pressure cycles (minimum 22 500 or 30 000 pressure cycles, respectively), then it shall be necessary to repeat the batch pressure cycle test frequency in a) for a minimum 10 production batches in order to re-establish the reduced frequency of batch pressure cycle testing in b) or c) above.

Should any cylinder in a), b), or c) above fail to meet the minimum cycle life requirement of 1 000 cycles multiplied by the specified service life in years (minimum 15 000 cycles), then the cause of failure shall be determined and corrected following the procedures in 8.9. 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, then the batch shall be rejected.

8.7 Tests on every cylinder

Production examinations and tests shall be carried out on all cylinders produced in a batch. Non-destructive examinations shall be carried out in accordance with a standard acceptable to the Inspector.

Each cylinder shall be examined during manufacture and after completion, as follows:

- a) by NDE of metallic liners in accordance with annex B or demonstrated equivalent method to verify that the maximum defect size does not exceed the size specified in the design as determined in accordance with 8.3.4. The NDE method shall be capable of detecting the maximum size allowed;
- b) to verify that the critical dimensions and mass of the completed cylinders and of the liners and overwrapping are within design tolerances;
- c) to verify compliance with 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 markings;
- e) by hardness tests of metallic liners in accordance with A.8 carried out after the final heat treatment; the values thus determined shall be in the range specified for the design;
- f) by hydraulic test of finished cylinders in accordance with A.11, option 1. The manufacturer shall establish the appropriate limit of permanent volumetric expansion for the test pressure used, but in no case shall the permanent expansion exceed 5 % of the total volumetric expansion measured under the test pressure.

8.8 Batch acceptance certificate

If the results of batch testing in accordance with 8.6 and 8.7 are satisfactory, the manufacturer and the Inspector shall sign an acceptance certificate. An example of an acceptance certificate (referred to as a "Report of Manufacture and Certificate of Conformance") is given in Annex E.

8.9 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 as follows to the satisfaction of the Inspector:

- a) if there is evidence of a fault in carrying out a test, or an error of measurement, a further test shall be performed; if the result of this test is satisfactory, the first test shall be ignored;
- b) if the test has been carried out in a satisfactory manner, the cause of test failure shall be identified.
 - 1) If the failure is considered to be due to the heat treatment applied, the manufacturer may subject all the cylinders implicated by the failure to a further heat treatment 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; however if the failure occurs sporadically in a test applied to every cylinder, then only those cylinders which fail the test shall require re-heat treatment and re-testing.
 - Whenever liners 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.

- 2) If the failure is due to a cause other than the heat treatment applied, 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.

9 Requirements for type CNG-4 all-composite cylinders

9.1 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 are capable of consistently passing the materials, design qualification, production and batch tests specified in this International Standard.

The design shall ensure a “leakage-before-break” failure mode under feasible degradation of pressure parts during normal service.

9.2 Materials

9.2.1 General requirements

Materials used shall be suitable for the service conditions specified in clause 4. The design shall ensure that incompatible materials are not in contact.

9.2.2 Resins

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

The glass transition temperature of the resin material shall be determined in accordance with ASTM D 3418-99.

9.2.3 Fibres

Structural reinforcing filament material types shall be glass fibre, aramid fibre or carbon fibre. If carbon fibre reinforcement is used the design shall incorporate a means of preventing galvanic corrosion of metallic components of the cylinder.

The manufacturer shall keep on file the published specifications for composite materials, the material manufacturer's recommendations for storage, conditions and shelf life, and the material manufacturer's certification that each shipment conforms to said specification requirements. The fibre manufacturer shall certify that the fibre material properties conform to the manufacturer's specifications for the product.

9.2.4 Plastic liners

The polymeric material shall be compatible with the service conditions specified in clause 4

9.2.5 Metal end bosses

The metal end bosses connected to the non-metallic liner shall be of a material compatible with the service conditions specified in clause 4.

9.3 Design requirements

9.3.1 Test pressure

The minimum test pressure used in manufacture shall be 300 bar (1,5 times working pressure).

9.3.2 Burst pressures and fibre stress ratios

The minimum actual burst pressure shall be not less than the values given in Table 9. The composite over-wrap shall be designed for high reliability under sustained loading and cyclic loading. This reliability shall be achieved by meeting or exceeding the composite reinforcement stress ratio values given in Table 9. Stress ratio is defined as the stress in the fibre at the specified minimum burst pressure divided by the stress in the fibre at working pressure. The burst ratio is defined as the actual burst pressure of the cylinder divided by the working pressure.

For type CNG-4 designs, the stress ratio is equal to the burst ratio.

Verification of the stress ratios may also be performed using strain gauges. An acceptable method is outlined in annex G.

Table 9 — Minimum actual burst values and stress ratios for type CNG-4 cylinders

Fibre type	Stress Ratio	Burst Pressure bar
Glass	3,65	730
Aramid	3,10	620
Carbon	2,35	470
Hybrid	a	
a Stress ratios and burst pressures shall be calculated in accordance with 9.3.2.		

9.3.3 Stress analysis

A stress analysis shall be performed to justify the minimum design wall thicknesses. It shall include the determination of the stresses in liners and fibres of composite designs.

The stresses in the tangential and longitudinal direction of the cylinder in the composite and in the liner shall be calculated. The pressures used for these calculations shall be 0 bar, 200 bar, test pressure and design burst pressure. The calculations shall use suitable analysis techniques to establish stress distribution throughout the cylinder.

9.3.4 Openings

Openings are permitted in the end bosses only. The centre line of openings shall coincide with the longitudinal axis of the cylinder.

9.3.5 Fire protection

The cylinder design shall be protected with pressure relief devices. The cylinder, its materials, pressure relief devices 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 be approved to a standard acceptable to the Inspector in the country of use.

9.4 Construction and workmanship

9.4.1 General

The composite cylinder shall be manufactured from a liner over-wrapped with continuous filament windings. Fibre winding operations shall be computer or mechanically controlled. The fibres shall be applied under controlled tension during winding. After winding is complete, thermosetting resins shall be cured by heating, using a predetermined and controlled time-temperature profile.

9.4.2 Neck threads

Threads shall be clean cut, even, without surface discontinuities, to gauge and comply with International Standards acceptable to the Inspector.

9.4.3 Curing of thermosetting resins

The curing temperature for thermosetting resins shall be at least 10 °C below the softening temperature of the plastic liner.

9.4.4 Exterior environmental protection

The exterior of cylinders shall meet the requirements of the acid environment test described in A.14. Exterior protection may be provided by using any of the following:

- a) a surface finish giving adequate protection (e.g. metal sprayed on to aluminium, anodizing); or
- b) the use of a suitable fibre and matrix material (e.g. carbon fibre in resin); or
- c) a protective coating (e.g. organic coating, paint); if exterior coating is part of the design, the requirements of A.9 shall be met; or
- d) a covering impervious to the chemicals listed in A.14.

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 to ensure the continued integrity of the cylinder.

Manufacturers are advised that an environmental performance test that evaluates the suitability of coating systems is provided in annex F.

9.5 Prototype testing procedure

9.5.1 General

Prototype testing shall be conducted on each new design, on finished cylinders which are representative of normal production and complete with identification marks. The test cylinders or liners shall be selected and the prototype tests detailed in 9.5.2 witnessed by the Inspector. If more cylinders or liners are subjected to the tests than are required by this International Standard, all results shall be documented.

9.5.2 Prototype tests

9.5.2.1 Tests required

In the course of the type approval, the Inspector shall select the necessary cylinders or liners for testing and witness the following tests:

- the tests specified in 9.5.2.2 (material tests), on 1 liner;
- the test specified in 9.5.2.3 (hydrostatic pressure burst test) on 3 cylinders;
- the test specified in 9.5.2.4 (ambient temperature pressure cycling test) on 2 cylinders;
- the test specified in 9.5.2.5 (LBB test) on 3 cylinders;
- the test specified in 9.5.2.6 (bonfire test) on 1 or 2 cylinders as appropriate;
- the test specified in 9.5.2.7 (penetration test) on 1 cylinder;
- the test specified in 9.5.2.8 (acid environment test) on 1 cylinder;
- the test specified in 9.5.2.9 (flaw tolerance test) on 1 cylinder;
- the test specified in 9.5.2.10 (high temperature creep test), where appropriate, on 1 cylinder;
- the test specified in 9.5.2.11 (accelerated stress rupture test), on 1 cylinder;
- the test specified in 9.5.2.12 (extreme temperature pressure cycling test) on 1 cylinder;
- the test specified in 9.5.2.13 (resin shear strength) on 1 sample coupon representative of the composite overwrap;
- the test specified in 9.5.2.14 (drop test) on at least 1 cylinder;
- the test specified in 9.5.2.15 (boss torque test) on 1 cylinder;
- the test specified in 9.5.2.16 (permeation test) on 1 cylinder;
- the test specified in 9.5.2.17 (natural gas cycling test) on 1 cylinder.

9.5.2.2 Material tests for plastic liners

The tensile yield strength and ultimate elongation shall be determined in accordance with A.22 and shall meet the requirements therein.

The softening temperature shall be determined in accordance with A.23 and shall meet the requirements therein.

The resistance to high temperature creep shall be determined in accordance with A.18 and shall meet the requirements therein.

9.5.2.3 Hydrostatic pressure burst test

Three cylinders shall be hydrostatically pressurized to failure in accordance with A.12. The cylinder burst pressures shall exceed the specified minimum burst pressure established by the stress analysis for the design, in accordance with Table 9, and in no case less than the value necessary to meet the stress ratio requirements of 9.3.2.

9.5.2.4 Ambient temperature pressure cycling test

Two cylinders shall be pressure cycle tested at ambient temperature in accordance with A.13 to failure, or to a minimum of 45 000 cycles. The cylinders shall not fail before reaching the specified service life in years multiplied by 1 000 cycles. Cylinders exceeding 1 000 cycles multiplied by the specified service life in years shall fail by leakage and not by rupture. Cylinders which do not fail within 45 000 cycles shall be destroyed either by continuing the cycling until failure occurs, or by hydrostatically pressurizing to burst. Cylinders exceeding 45 000 cycles are permitted to fail by rupture. The number of cycles to failure and the location of the failure initiation shall be recorded.

9.5.2.5 Leak-before-break (LBB) test

LBB tests shall be conducted in accordance with A.6 and meet the requirements therein.

9.5.2.6 Bonfire test

One or two cylinders as appropriate shall be tested in accordance with A.15 and meet the requirements therein.

9.5.2.7 Penetration test

One cylinder shall be tested in accordance with A.16 and meet the requirements therein.

9.5.2.8 Acid environment test

One cylinder shall be tested in accordance with A.14 and meet the requirements therein.

An optional environmental test is included in annex F.

9.5.2.9 Flaw tolerance tests

One cylinder shall be tested in accordance with A.17 and meet the requirements therein.

9.5.2.10 High temperature creep test

In designs where the glass transition temperature of the resin does not exceed 102 °C, one cylinder shall be tested in accordance with A.18 and meet the requirements therein.

9.5.2.11 Accelerated stress rupture test

One cylinder shall be tested in accordance with A.19 and meet the requirements therein.

9.5.2.12 Extreme temperature pressure cycling test

One cylinder shall be tested in accordance with A.7 and meet the requirements therein.

9.5.2.13 Resin shear strength

Resin materials shall be tested in accordance with A.26, and meet the requirements therein.

9.5.2.14 Drop test

One (or more) finished cylinders shall be drop tested in accordance with A.20 and meet the requirements therein.

9.5.2.15 Boss torque test

One cylinder shall be tested in accordance with A.25 and meet the requirements therein.

9.5.2.16 Permeation test

One cylinder shall be tested for permeation in accordance with A.21 and meet the requirements therein.

9.5.2.17 Natural gas cycling test

One cylinder shall be tested in accordance with A.27 and meet the requirements therein.

9.5.3 Change of design

A design change is any change in the selection of structural materials or dimensional change not attributable to normal manufacturing tolerances.

Minor design changes shall be permitted to be qualified through a reduced test programme. Changes of design specified in Table 10 shall require design qualification testing as specified in the table.

Table 10 — Change of design for type CNG-4 cylinders

Design change	Type of test											
	Hydrostatic burst	Pressure cycling at ambient temperature	Bonfire	Penetration	Environmental	Flaw tolerance	High temperature creep	Stress rupture	Drop	Boss torque	Permeation	CNG cycling
	Clause											
	A.12	A.13	A.15	A.16	A.14	A.17	A.18	A.19	A.20	A.25	A.21	A.27
Fibre manufacturer	X	X	—	—	—	—	X	X	X	X	X	X
Plastic liner material	X	X	X	X	X	X	X	X	X	X	X	X
Fibre material	X	X	X	X	X	X	X	X	X	X	X	X
Resin material	—	—	—	X	X	X	X	X	X	—	—	—
Diameter change ≤ 20 %	X	X	—	—	—	—	—	—	—	—	—	—
Diameter change > 20 %	X	X	X	X	—	X	—	—	X	—	—	—
Length change ≤ 50 %	X	—	X ^a	—	—	—	—	—	—	—	—	—
Length change > 50 %	X	X	X ^a	—	—	—	—	—	X	—	—	—
Working pressure change ≤ 20 % ^b	X	X	—	—	—	—	—	—	—	—	—	—
Dome shape	X	X	—	—	—	—	—	—	—	X	X	X
Opening size	X	X	—	—	—	—	—	—	—	—	—	—
Coating change	—	—	—	—	X	—	—	—	—	—	—	—
End boss design	—	—	—	—	—	—	—	—	—	X	X	X
Change in manuf. process	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.												

^a Test only required when length increases.^b Only when thickness change proportional to diameter and/or pressure change.

9.6 Batch tests

9.6.1 General requirements

Batch testing shall be conducted on finished cylinders which are representative of normal production and are complete with identification marks. The cylinder(s) and liner(s) 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.

9.6.2 Required tests

9.6.2.1 At least the following tests shall be carried out on each batch of cylinders:

- a) on one cylinder:
 - 1) one hydrostatic pressure burst test in accordance with A.12.
 - If the burst pressure is less than the minimum calculated burst pressure, the procedures specified in 9.9 shall be followed.
- b) on one cylinder, or liner, or witness sample representative of a finished cylinder:
 - 1) a check of the critical dimensions against the design (see 5.2.4.1);
 - 2) one tensile test of the plastic liner in accordance with A.22; the test results shall satisfy the requirements of the design (see 5.2.4.1);
 - 3) the melt temperature of the plastic liner shall be tested in accordance with A.23, and meet the requirements of the design;
 - 4) when a protective coating is a part of the design, a coating batch test in accordance with A.24 to meet the requirements therein. Where the coating fails to meet the requirements of A.24, the batch shall be 100 % inspected to remove similarly defectively coated cylinders. The coating on all defectively coated cylinders may be stripped using a method that does not affect the integrity of the composite wrapping then recoated. The coating batch test shall then be repeated.

All cylinders or liners represented by a batch test which fails to meet the requirements specified shall follow the procedures specified in 9.9.

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

- a) initially, on one cylinder from each batch the end boss shall be torque tested in accordance with A.25. The cylinder shall then be pressure cycled for a total of 1 000 times the specified service life in years, with a minimum 15 000 cycles. Following the required pressure cycling, the cylinder shall be leak tested in accordance with the method described in A.10, and meet the requirements therein;
- 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 9.5.3), none of the pressure cycled cylinders in a) above leaks or ruptures in less than 1 500 cycles multiplied by the specified life in years (minimum 22 500 cycles) then the pressure cycle test may be reduced to one cylinder from every 5 batches of production;
- c) if on 10 sequential production batches of a design family, none of the pressure cycled cylinders in a) above leaks or ruptures in less than 2 000 cycles multiplied by the specified service life in years (minimum 30 000 cycles) then the pressure cycle test can be reduced to one cylinder from every 10 batches of production;

- d) should more than 3 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 b) or c) above;
- e) should any reduced frequency pressure cycle test cylinder in b) or c) above fail to meet the required number of pressure cycles (minimum 22 500 or 30 000 pressure cycles, respectively), then it shall be necessary to repeat the batch pressure cycle test frequency in a) for a minimum of 10 production batches in order to re-establish the reduced frequency of batch pressure cycle testing in b) or c) above.

Should any cylinder in a), b), or c) above fail to meet the minimum cycle life requirement of 1 000 cycles multiplied by the specified service life in years (minimum 15 000 cycles), then the cause of failure shall be determined and corrected following the procedures in 9.9. 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, then the batch shall be rejected.

9.7 Tests on every cylinder

Production examinations and tests shall be carried out on all cylinders produced in a batch.

Each cylinder shall be examined during manufacture and after completion, as follows:

- a) by inspection of liners to confirm that the maximum defect size present is smaller than the size specified in the design;
- b) to verify that the critical dimensions and mass of the completed cylinder and of any liner and overwrapping are within design tolerances;
- c) to verify compliance with specified surface finish;
- d) to verify the markings;
- e) by hydraulic test of finished cylinders in accordance with A.11, option 1. The manufacturer shall define the appropriate limit of elastic expansion for the test pressure used, but in no case shall the elastic expansion of any cylinder exceed the average batch value by more than 10 %;
- f) by leak test in accordance with A.10, and shall meet the requirements therein.

9.8 Batch acceptance certificate

If the results of batch testing according to 9.6 and 9.7 are satisfactory, the manufacturer and the Inspector shall sign an acceptance certificate. An example of an acceptance certificate (referred to as a "Report of Manufacture and Certificate of Conformance") is given in annex E.

9.9 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 as follows:

- 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.
 - All defective cylinders shall be 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.

- The new batch shall be retested. All 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.

10 Marking

On each cylinder the manufacturer shall provide clear permanent markings not less than 6 mm high. Marking shall be made either by labels incorporated into resin coatings, labels attached by adhesive, low stress stamps used on the thickened ends of type CNG-1 and CNG-2 designs, or any combination of the above. Adhesive labels and their application shall be in accordance with ISO 7225, or an equivalent standard acceptable to the Inspector in the country of use. Multiple labels are allowed and should be located such that they are not obscured by mounting brackets.

Each cylinder complying with this International Standard shall be marked as follows:

- a) the words "CNG ONLY";
- b) the words "DO NOT USE AFTER XX/XXXX", where XX/XXXX identifies the month and year of expiry.
 - The period between the dispatch date and the expiry date shall not exceed the specified service life. The expiry date may be applied to the cylinder at the time of dispatch, provided that the cylinders have been stored in a dry location without internal pressure;
- c) manufacturers' identification;
- d) cylinder identification (a serial number unique for every cylinder);
- e) working pressure at temperature;
- f) reference to this International Standard, "ISO 11439:2000", along with cylinder type and certification registration number (if applicable);
- g) the words "Use only a manufacturer-approved PRD";
- h) when labels are used, a unique identification number and the manufacturer's identification stamped on an exposed metal surface to permit tracing in the event that the label is destroyed;
- i) date of manufacture (month and year);
- j) any additional markings as required by the Inspector of the country(ies) of use.

The markings shall be placed in the listed sequence but the specific arrangement may be varied to match the space available. An acceptable example is:

CNG ONLY
DO NO USE AFTER 3/2009
Manufacturer/Identification number
200 bar/15 °C
ISO 11439:2000 CNG-2 (registration no.)
"Use only manufacturer-approved PRD"
Manufacture date 08/98

11 Preparation for dispatch

Prior to dispatch from the manufacturer's shop, every cylinder shall be internally cleaned and dried. Cylinders not immediately closed by the fitting of a valve, and safety devices if applicable, shall have plugs, which prevent entry of moisture and protect threads, fitted to all openings. A corrosion inhibitor (e.g. oil-containing) shall be sprayed into all steel cylinders and liners prior to dispatch.

The manufacturer's statement of service and all necessary information and instructions to ensure the proper handling, use and in-service inspection of the cylinder shall be supplied to the purchaser. The statement of service shall be in accordance with 5.2.3. Guidance on the content of the instructions is given in annex H.

Annex A **(normative)**

Test methods and criteria

A.1 Tensile tests for steel and aluminium cylinders and liners

A tensile test shall be carried out on material taken from the cylindrical part of the finished cylinder or liner using a rectangular test piece shaped in accordance with the method described in ISO 9809-1 for steel and ISO 7866 for aluminium. The two faces of the test piece representing the inside and outside surface of the cylinder shall not be machined.

The tensile test shall be carried out in accordance with ISO 6892.

The tensile strength shall meet the manufacturer's design specifications.

For steel cylinders and liners, the elongation shall be at least 14 %.

For aluminium alloy cylinders and liners of type 1 or type 2 construction, the elongation shall be at least 12 %.

For aluminium alloy liners of type 3 construction, the elongation shall meet the manufacturer's design specifications.

NOTE Attention is drawn to the method of measurement of elongation described in ISO 6892, particularly in cases where the tensile test piece is tapered, resulting in a point of fracture away from the middle of the gauge length.

A.2 Impact test for steel cylinders and steel liners

The impact test shall be carried out on material taken from the cylindrical part of the finished cylinder or liner on three test pieces in accordance with ISO 148.

The impact test pieces shall be taken in the directions given in Table A.1 from the wall of the cylinder. The notch shall be perpendicular to the face of the cylinder wall. For longitudinal tests the test piece shall be machined all over (on six faces). If the wall thickness does not permit a final test piece width of 10 mm, the width shall be as near as practicable to the nominal thickness of the cylinder wall. Test pieces taken in the transverse direction shall be machined on four faces only, the inner and outer face of the cylinder wall shall be unmachined.

The impact values shall be not less than those specified in Table A.1.

A.3 Sulfide stress cracking test for steel

Except as identified in the following, testing shall be conducted in accordance with Method A - NACE Standard Tensile Test procedures, as described in NACE Standard TM0177-96. Tests shall be conducted on a minimum of three tensile specimens with a gauge diameter of 3,81 mm (0,150 inches) machined from the wall of a finished cylinder or liner. The specimens shall be placed under a constant tensile load equal to 60 % of the specified minimum yield strength of the steel, immersed in a solution of distilled water buffered with 0,5 % (mass fraction) sodium acetate trihydrate and adjusted to an initial pH of 4,0, using acetic acid. The solution shall be continuously saturated at room temperature and pressure with 0,414 kPa (0,06 psia) hydrogen sulfide (balance nitrogen). The tested specimens shall not fail within a test duration of 144 hours.

Table A.1 — Impact test acceptance values

Cylinder diameter D , mm		> 140			≤ 140
Direction of testing		Transverse			Longitudinal
Width of test piece, mm		3 to 10	> 5 to 7,5	> 7,5 to 10	3 to 10
Test temperature, °C		– 50			– 50
Impact strength, J/cm ²	Mean of 3 specimens	30	35	40	60
	Individual specimen	24	28	32	48

A.4 Corrosion tests for aluminium

Corrosion tests for aluminium alloys shall be carried out in accordance with annex A of ISO 7866:1999 and meet the requirements therein.

A.5 Sustained load cracking (SLC) tests for aluminium

The resistance to SLC shall be carried out in accordance with annex B of ISO 7866:1999 and shall meet the requirements therein.

A.6 Leak-before-break (LBB) test

Three finished cylinders shall be pressure cycled between 20 bar and 300 bar at a rate not to exceed 10 cycles per minute in accordance with A.13.

All cylinders shall either fail by leakage or exceed 45 000 pressure cycles.

A.7 Extreme temperature pressure cycling

Finished cylinders, with the composite wrapping free of any protective coating, shall be cycle tested, as follows:

- condition for 48 h at zero pressure, 65 °C or higher, and 95 % or greater relative humidity. The intent of this requirement shall be deemed met by spraying with a fine spray or mist of water in a chamber held at 65 °C;
- hydrostatically pressurize for 500 cycles multiplied by the specified service life in years between 20 bar and 260 bar at 65 °C or higher, and 95 % or greater relative humidity;
- condition the cylinder and fluid at – 40 °C or lower as measured in the fluid and on the cylinder surface;
- pressurize from 20 bar to 200 bar for 500 cycles multiplied by the specified service life in years at – 40 °C or lower. Adequate recording instrumentation shall be provided to ensure the minimum temperature of the fluid is maintained during the low temperature cycling.

The pressure cycling rate of b) shall not exceed 10 cycles per minute. The pressure cycling rate of d) shall not exceed 3 cycles per minute unless a pressure transducer is installed directly within the cylinder.

During this pressure cycling, the cylinder shall show no evidence of rupture, leakage or fibre unravelling.

Following pressure cycling at extreme temperatures, cylinders shall be hydrostatically pressured to failure in accordance with A.12, and achieve a minimum burst pressure of 85 % of the minimum design burst pressure. For type CNG-4 designs, prior to the hydrostatic burst test the cylinder shall be leak tested in accordance with A.10.

A.8 Brinell hardness test

Hardness tests shall be carried out on the parallel wall of each cylinder or liner in accordance with ISO 6506-1 at the rate of one test per metre length of parallel wall. The test shall be carried out after the final heat treatment and the hardness values thus determined shall be in the range specified for the design.

A.9 Coating tests

Coatings shall be evaluated using the following test methods, or using equivalent standards acceptable to the Inspector in the country of use:

- a) adhesion testing, in accordance with ISO 4624:—, using method A or B as applicable. The coating shall exhibit an adhesion rating of either 4A or 4B, as applicable;
- b) flexibility, in accordance with ASTM D522-93, using test method B with a 12,7 mm (0,5 in) mandrel at the specified thickness at – 20 °C. Samples for the flexibility test shall be prepared in accordance with ASTM D522-93. There shall be no visually apparent cracks;
- c) impact resistance, in accordance with ASTM D2794-93. The coating at room temperature shall pass a forward impact test of 18 J (13,3 ft lbs);
- d) chemical resistance, in accordance with ASTM D1308-87 except as identified in the following. The tests shall be conducted using the open spot test method and 100 h exposure to a 30 % sulfuric acid solution (battery acid with a specific gravity of 1,219) and 24 h exposure to a polyalkylene glycol (e.g. brake fluid). There shall be no evidence of lifting, blistering or softening of the coating. The adhesion shall meet a rating of 3 when tested in accordance with ISO 4624:—;
- e) minimum 1 000 h exposure, in accordance with ASTM G53-93. There shall be no evidence of blistering, and adhesion shall meet a rating of 3 when tested in accordance with ISO 4624:—. The maximum gloss loss allowed is 20 %;
- f) minimum 500 h exposure in accordance with ISO 9227. Undercutting shall not exceed 2 mm at the scribe mark, there shall be no evidence of blistering and adhesion shall meet a rating of 3 when tested in accordance with ISO 4624:—;
- g) resistance to chipping at room temperature, in accordance with ASTM D3170-87. The coating shall have a rating of 7A or better, and there shall be no exposure of the substrate.

A.10 Leak test

Type CNG-4 designs shall be leak tested using the following procedure (or an alternative acceptable to the Inspector in the country of use):

- a) thoroughly dry the cylinders;
- b) pressurize the cylinders to working pressure with dry air or nitrogen containing a detectable gas such as helium.

Any leakage detected shall be cause for rejection.

NOTE Leakage is the release of gas through a crack, pore, unbond or similar defect. Permeation through the wall in compliance with A.21 is not considered to be leakage.

A.11 Hydraulic test

Any internal pressure applied after autofrettage and prior to the hydrostatic test shall not exceed 90 % of the hydrostatic test pressure.

One of the following two options shall be used:

Option 1. Volumetric expansion test

- a) The cylinder shall be hydrostatically tested to at least 1,5 times working pressure. In no case shall the test pressure exceed the autofrettage pressure.
- b) Pressure shall be maintained for 30 s and sufficiently longer to ensure complete expansion. Any internal pressure applied after autofrettage and prior to the hydrostatic test shall not exceed 90 % of the hydrostatic test pressure. If the test pressure cannot be maintained due to failure of the test apparatus, it is permissible to repeat the test at a pressure increased by 7 bar. No more than 2 such repeat tests are permitted.
- c) Any cylinders not meeting the defined rejection limit shall be rejected and rendered unserviceable.

Option 2. Proof pressure test

The hydrostatic pressure in the cylinder shall be increased gradually and regularly until the test pressure, at least 1,5 times working pressure, is reached. The cylinder test pressure shall be maintained for at least 30 s to establish that there are no leaks.

A.12 Hydrostatic pressure burst test

The rate of pressurization shall not exceed 14 bar/s at pressures in excess of 80 % of the design burst pressure. If the rate of pressurization at pressures in excess of 80 % of the design burst pressure exceeds 3,5 bar/s, then either the cylinder shall be placed schematically between the pressure source and the pressure measurement device, or there shall be a 5 s hold at the minimum design burst pressure.

The minimum required (calculated) burst pressure shall be at least 450 bar, and in no case less than the value necessary to meet the stress ratio requirements. Actual burst pressure shall be recorded. Rupture may occur in either the cylindrical region or the dome region of the cylinder.

A.13 Ambient temperature pressure cycling

Pressure cycling shall be performed in accordance with the following procedure:

- a) fill the cylinder to be tested with a non-corrosive fluid such as oil, inhibited water or glycol;
- b) cycle the pressure in the cylinder between 20 bar and 260 bar at a rate not exceeding 10 cycles per minute.

The number of cycles to failure shall be reported, along with the location and description of the failure initiation.

A.14 Acid environment test

On a finished cylinder the following test procedure shall be applied:

- a) expose a 150 mm diameter area on the cylinder surface for 100 h to a 30 % sulfuric acid solution (battery acid with a specific gravity of 1,219) whilst the cylinder is hydrostatically pressurized to 260 bar;
- b) pressurize the cylinder to burst in accordance with the procedure defined in A.12.

The burst pressure shall exceed 85 % of the minimum design burst pressure.

A.15 Bonfire test

A.15.1 General

The bonfire test is designed to demonstrate that finished cylinders, complete with the fire protection system (cylinder valve, pressure relief devices and/or integral thermal insulation) specified in the design, will prevent the rupture of the cylinder when tested under the specified fire conditions.

Precautions shall be taken during fire testing in the event that cylinder rupture occurs.

A.15.2 Cylinder set-up

The cylinder shall be placed horizontally with the cylinder bottom approximately 100 mm above the fire source.

Metallic shielding shall be used to prevent direct flame impingement on cylinder valves, fittings, and/or pressure relief devices. The metallic shielding shall not be in direct contact with the specified fire protection system (pressure relief devices or cylinder valve).

Any failure during the test of a valve, fitting or tubing that is not part of the intended protection system for the design shall invalidate the result.

A.15.3 Fire source

A uniform fire source of 1,65 m length shall provide direct flame impingement on the cylinder surface across its entire diameter.

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 air pollution concerns. The arrangement of the fire shall be recorded in sufficient detail to ensure that the rate of heat input to the cylinder is reproducible.

Any failure or inconsistency of the fire source during a test shall invalidate the result.

A.15.4 Temperature and pressure measurements

Surface temperatures shall be monitored by at least three thermocouples located along the bottom of the cylinder and spaced not more than 0,75 m apart.

Metallic shielding shall be used to prevent direct flame impingement on the thermocouples. Alternatively, thermocouples may be inserted into blocks of metal measuring less than 25 mm square.

Thermocouple temperatures and the cylinder pressure shall be recorded at intervals of every 30 s or less during the test.

A.15.5 General test requirements

The cylinder shall be pressurized to working pressure with natural gas or compressed air and tested in the horizontal position at working pressure and at 25 % of working pressure if a thermally activated PRD is not used.

Immediately following ignition, the fire shall produce flame impingement on the surface of the cylinder along the 1,65 m length of the fire source and across the cylinder diameter.

Within 5 min of ignition the temperature at least one thermocouple shall indicate a temperature ≥ 590 °C. This minimum temperature shall be maintained for the remainder of the test.

For cylinders of length 1,65 m or less, the centre of the cylinder shall be positioned over the centre of the fire source.

For cylinders of length greater than 1,65 m, the cylinder shall be positioned as follows:

- a) if the cylinder is fitted with a pressure relief device at one end, the fire source shall commence at the opposite end of the cylinder;
- b) if the cylinder is fitted with pressure relief devices at both ends, or at more than one location along the length of the cylinder, the centre of the fire source shall be centred midway between the pressure relief devices that are separated by the greatest horizontal distance;
- c) if the cylinder is additionally protected using thermal insulation, then two fire tests at service pressure shall be performed, one with the fire centred midway along the cylinder length, and the other with the fire commencing at one of the ends of a second cylinder.

A.15.6 Acceptable results

The cylinder shall vent through a pressure relief device.

A.16 Penetration tests

A cylinder pressurized to 200 bar $\pm$ 10 bar with compressed gas shall be penetrated by an armour piercing bullet with a diameter of 7,62 mm or greater. The bullet shall completely penetrate at least one side wall of the cylinder. For type CNG-2, CNG-3 and CNG-4 designs, the projectile shall impact the sidewall at an approximate angle of 45°. The cylinder shall not rupture.

A.17 Composite flaw tolerance tests

For type CNG-2, CNG-3 and CNG-4 designs only, one finished cylinder, complete with protective coating, shall have flaws cut into the composite in the longitudinal direction. The flaws shall be greater than the visual inspection limits as specified by the manufacturer. As a minimum, one flaw shall be 25 mm long and 1,25 mm in depth, and another flaw shall be 200 mm long and 0,75 mm in depth, cut in the longitudinal direction into the cylinder sidewall.

The flawed cylinder shall then be pressure cycled between 20 bar and 260 bar at ambient temperature, initially for 3 000 cycles, then followed by an additional 12 000 cycles.

The cylinder shall not leak or rupture within the first 3 000 cycles, but may fail by leakage during the further 12 000 cycles. All cylinders which complete this test shall be destroyed.

A.18 High temperature creep test

This test is required for all type CNG-4 designs, and all type CNG-2 and CNG-3 designs in which the glass transition temperature of the resin matrix does not exceed 102 °C. One finished cylinder shall be tested as follows:

- a) the cylinder shall be pressurized to 260 bar and held at a temperature of 100 °C for not less than 200 h;
- b) following the test, the cylinder shall meet the requirements of the hydrostatic expansion test (A.11), the leak test (A.10) and the hydrostatic pressure burst test (A.12).

A.19 Accelerated stress rupture test

For type CNG-2, CNG-3 and CNG-4 designs only, one cylinder shall be hydrostatically pressurized to 260 bar at 65 °C. The cylinder shall be held at this pressure and temperature for 1 000 h. The cylinder shall then be pressured to burst in accordance with the procedure described in A.12, except that the burst pressure shall exceed 85 % of the minimum design burst pressure.

A.20 Impact damage test

One or more finished cylinders shall be drop tested at ambient temperature without internal pressurization or attached valves. The surface on to which the cylinders are dropped shall be a smooth, horizontal concrete pad or flooring. One cylinder shall be dropped in a horizontal position with the bottom 1,8 m above the surface on to which it is dropped. One cylinder shall be dropped vertically on each end at a sufficient height above the floor or pad so that the potential energy is 488 J, 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 on to 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 shall be changed to maintain a minimum height of 0,6 m and a centre of gravity of 1,8 m.

Following the drop impact, the cylinders shall then be pressure cycled between 20 bar and 260 bar at ambient temperature, initially for 3 000 cycles, then followed by an additional 12 000 cycles.

The cylinder shall not leak or rupture within the first 3 000 cycles, but may fail by leakage during the further 12 000 cycles. All cylinders which complete this test shall be destroyed.

A.21 Permeation test

This test is only required on type CNG-4 designs. One finished cylinder shall be filled with compressed natural gas to working pressure, placed in an enclosed sealed chamber at ambient temperature, and monitored for leakage for 500 h. The permeation rate shall be less than 0,25 ml of natural gas per hour per litre water capacity of the cylinder. The cylinder shall be sectioned and the internal surfaces inspected for any evidence of cracking or deterioration.

A.22 Tensile properties of plastics

The tensile yield strength and ultimate elongation of plastic liner material shall be determined at – 50 °C in accordance with ISO 527-2.

The test results shall demonstrate the ductile properties of the plastic liner material at temperatures of – 50 °C or lower by meeting the values specified by the manufacturer.

A.23 Softening temperature of plastics

Polymeric materials from finished liners shall be tested in accordance with a method described in ISO 306.

The softening temperature shall be at least 100 °C.

A.24 Coating batch tests

A.24.1 Coating thickness

The thickness of the coating shall be measured in accordance with ISO 2808 and shall meet the requirements of the design.

A.24.2 Coating adhesion

The coating adhesion strength shall be measured in accordance with ISO 4624:—, and shall have a minimum rating of 4 when measured using either test method A or B, as appropriate.

A.25 Boss torque test

The body of the cylinder shall be restrained against rotation and a torque of twice the valve or PRD installation torque specified by the manufacturer shall be applied to each end boss of the cylinder. The torque shall be applied first in the direction of tightening a threaded connection, then in the untightening direction, and finally again in the tightening direction.

The cylinder shall then be subjected to a leak test in accordance with A.10.

A.26 Resin shear strength

Resin materials shall be tested on a sample coupon representative of the composite overwrap in accordance with ISO 14130, or an equivalent standard acceptable to the Inspector in the country of use. Following 24 h boiling in water the composite shall have a minimum shear strength of 13,8 MPa.

A.27 Natural gas cycling test

Special consideration shall be given to safety when conducting this test. Prior to conducting this test, cylinders of this design shall have successfully passed the test requirements of A.10 (leak test), A.12 (hydrostatic pressure burst test), A.13 (ambient temperature pressure cycling test) and A.21 (permeation test).

One finished type CNG-4 cylinder shall be pressure cycled using compressed natural gas between less than 20 bar and working pressure for 1 000 cycles. The filling time shall be 5 min maximum. Unless otherwise specified by the manufacturer, care should be taken to ensure that temperatures during venting do not exceed the defined service conditions.

The cylinder shall be leak tested in accordance with A.10 and meet the requirements therein. Following the completion of the natural gas cycling the cylinder shall be sectioned and the liner and liner/end boss interface inspected for evidence of any deterioration, such as fatigue cracking or electrostatic discharge.

Annex B **(normative)**

Ultrasonic inspection

B.1 Scope

This annex is based on techniques used by cylinder manufacturers. Other techniques of ultrasonic inspection may be used, provided these have been demonstrated to be suitable for the manufacturing method.

B.2 General requirements

The ultrasonic testing equipment shall be capable of at least detecting the reference standard as described in B.3.2. It shall be serviced regularly in accordance with the manufacturer's operating instructions to ensure that its accuracy is maintained. Inspection records and approval certificates for the equipment shall be maintained.

The operation of the test equipment shall be by trained personnel and supervised by qualified and experienced personnel certified to level 2 of ISO 9712:1999.

The outer and inner surfaces of any cylinder which is to be tested ultrasonically shall be in a condition suitable for an accurate and reproducible test.

For flaw detection the pulse echo system shall be used. For thickness measurement either the resonance method or the pulse echo system shall be used. Either contact or immersion techniques of testing shall be used.

A coupling method which ensures adequate transmission of ultrasonic energy between the testing probe and the cylinder shall be used.

B.3 Flaw detection of the cylindrical parts

B.3.1 Procedure

The cylinders to be inspected and the search unit shall have a rotating motion and translation relative to one another such that a helical scan of the cylinder is described. The velocity of rotation and translation shall be constant within $\pm 10\%$. The pitch of the helix shall be less than the width covered by the probe (at least a 10 % overlap shall be guaranteed) and be related to the effective beam width such as to ensure 100 % coverage at the velocity of rotation and translation used during the calibration procedure.

An alternative scanning method may be used for transverse defect detection, in which the scanning or relative movement of the probes and the work piece is longitudinal, the sweeping motion being such as to ensure a 100 % surface coverage with about 10 % overlap of the sweeps.

The cylinder wall shall be tested for longitudinal defects with the ultrasonic energy transmitted in both circumferential directions and for transverse defects in both longitudinal directions.

In this case, or when optional testing is carried out on the transition areas between the wall and neck and/or wall and base, this may be conducted manually if not carried out automatically.

The effectiveness of the equipment shall be periodically checked by passing a reference standard through the test procedure. This check shall be carried out at least at the beginning and end of each shift. If during this check the

presence of the appropriate reference notch is not detected then all cylinders tested subsequent to the last acceptance check shall be retested after the equipment has been reset.

B.3.2 Reference standard

A reference standard of convenient length shall be prepared from a cylinder of similar diameter and wall thickness range, and from material with the same acoustic characteristics and surface finish as the cylinder to be inspected. The reference standard shall be free from discontinuities which may interfere with the detection of the reference notches.

Reference notches, both longitudinal and transverse, shall be machined on the outer and inner surface of the standard. The notches shall be separated such that each notch can be clearly identified.

Dimensions and shape of notches are of crucial importance for the adjustment of the equipment (see Figures B.1 and B.2).

- the length of the notches (E) shall be no greater than 50 mm;
- the width (W) shall be no greater than twice the nominal depth (T). However, where this condition cannot be met a maximum width of 1 mm is acceptable;
- the depth of the notches (T) shall be $5\% \pm 0,75\%$ of the nominal thickness (S) with a minimum of 0,2 mm and a maximum of 1 mm, over the full length of the notch. Runouts at each end are permissible;
- the notch shall be sharp edged at its intersection with the surface of the cylinder wall. The cross section of the notch shall be rectangular except where spark erosion machining methods are used; then it is acknowledged that the bottom of the notch will be rounded;
- the shape and dimensions of the notch shall be demonstrated by an appropriate method.

B.4 Calibration of equipment

Using the reference standard described in B.3.2, the equipment shall be adjusted to produce clearly identifiable indications from inner and outer reference notches. The amplitude of the indications shall be as near equal as possible. The indication of smallest amplitude shall be used as the rejection level and for setting visual, audible, recording or sorting devices. The equipment shall be calibrated with the reference standard or probe, or both, moving in the same manner, in the same direction and at the same speed as will be used during the inspection of the cylinder. All visual, audible, recording or sorting devices shall operate satisfactorily at the test speed.

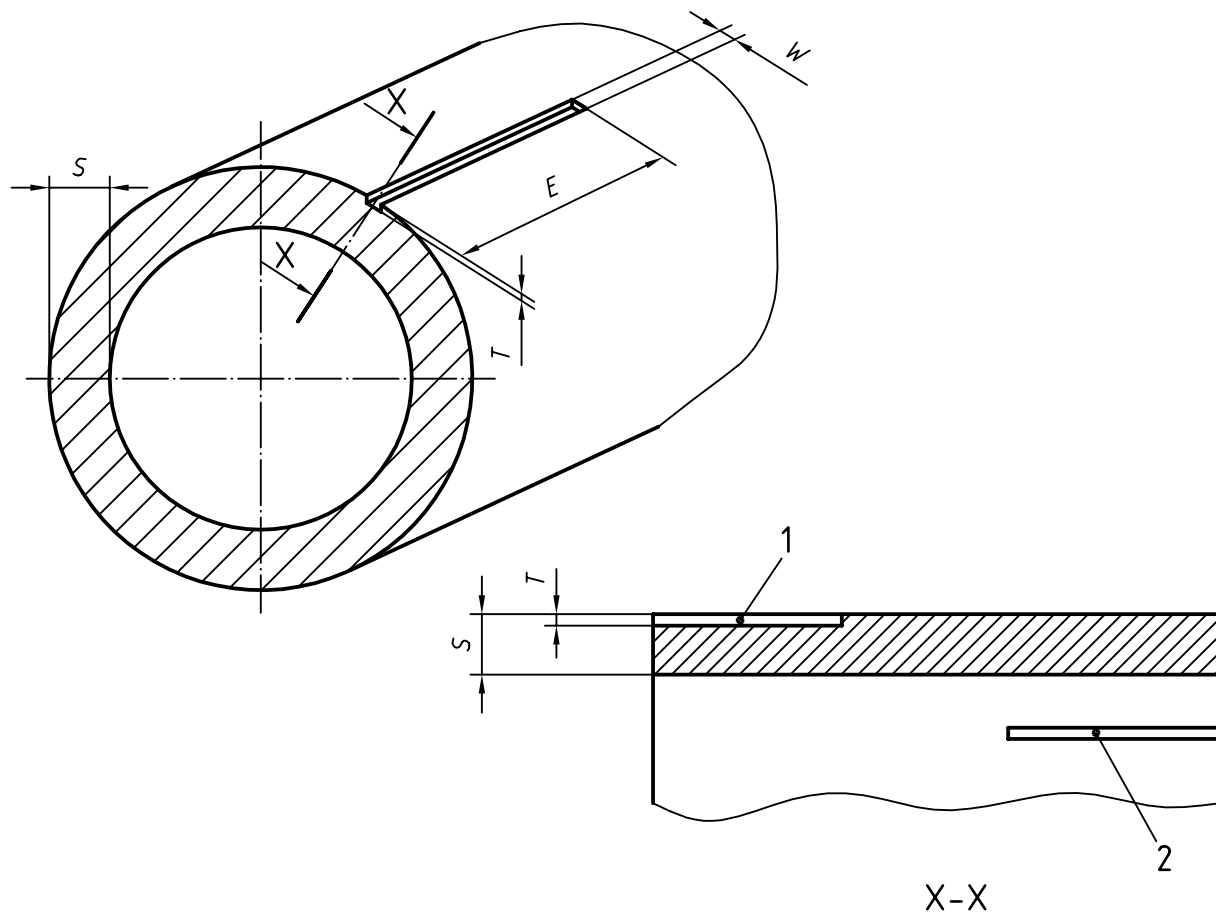
B.5 Wall thickness measurement

If the measurement of the wall thickness is not carried out at another stage of production, the cylindrical part shall be 100 % examined to ensure that the thickness is not less than the guaranteed minimum value.

B.6 Interpretation of results

Cylinders with indications which are equal to or greater than the lowest of the indications from the reference notches shall be withdrawn. Surface defects may be removed; after removal the cylinders shall be resubjected to ultrasonic flaw detection and thickness measurement.

Any cylinder which is shown to be below the guaranteed minimum wall thickness shall be rejected.

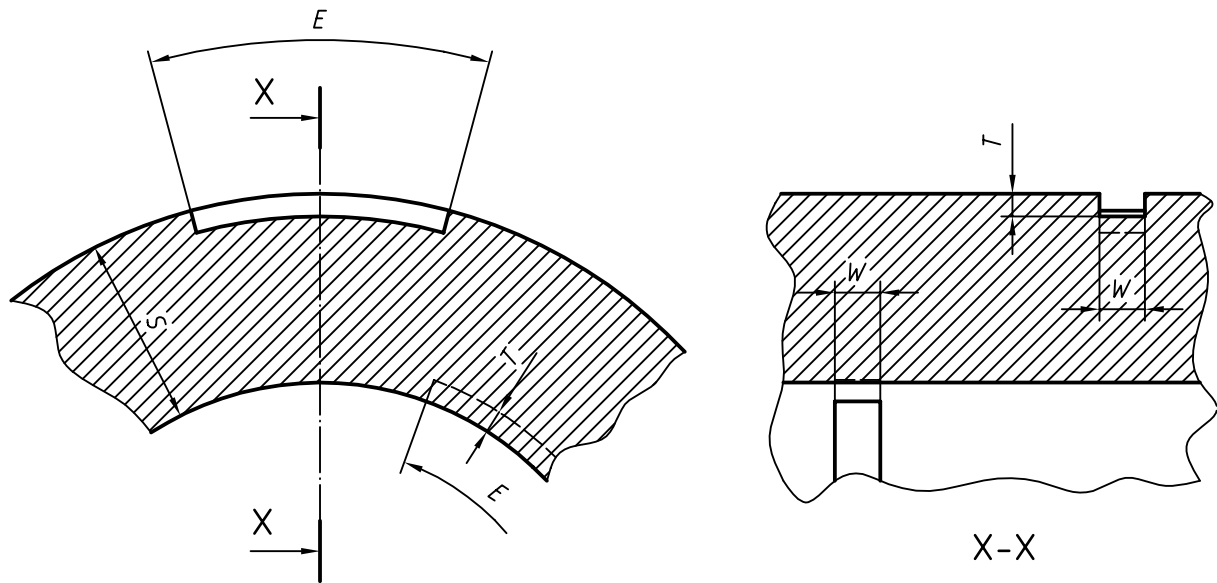


Key

- 1 External reference notch
- 2 Internal reference notch

NOTE $T \leq (5 \pm 0,75) \% S$ but $0,2 \text{ mm} \leq T \leq 1 \text{ mm}$
 $W \leq 2T$, but if not possible then $W \leq 1 \text{ mm}$
 $E \leq 50 \text{ mm}$

Figure B.1 — Design details and dimensions of the reference notches for longitudinal defects



NOTE $T \leq (5 \pm 0,75) \% S$ but $0,2 \text{ mm} \leq T \leq 1 \text{ mm}$
 $W \leq 2T$, but if not possible then $W \leq 1 \text{ mm}$
 $E \leq 50 \text{ mm}$

Figure B.2 — Schematic representation of the reference notches for circumferential defects

B.7 Certification

The ultrasonic testing shall be certified by the cylinder manufacturer.

Every cylinder, which has passed the ultrasonic testing in accordance with this specification shall be stamp-marked with the symbol "UT".

Annex C **(informative)**

Approval and certification procedures

C.1 General

Certification of the manufacturer, cylinder approval and monitoring of the quality control/inspection procedures is typically performed by either the regulatory authority or by an independent inspection authority approved and designated by the regulatory authority. This annex describes the processes involved in such procedures. There can be more than one independent inspection authority within a country and an inspection authority can be from another country.

C.2 Manufacturer's certification

To obtain certification in a country, the manufacturer applies to the regulatory authority for certification. The application contains documentation on design, process and quality control/inspection as required in clause 5.

The regulatory authority certifies the manufacturer by the following actions and issues a "certificate of approval":

- the regulatory authority carries out or causes to be carried out by an independent inspection authority, an on-site examination of the manufacturing plant, including equipment and quality control. This includes observations of manufacture, testing and inspection operations. This is to verify that the plant, equipment, personnel and systems are adequate to produce cylinders in accordance with this International Standard.
- the regulatory authority tests or causes to be tested cylinders from a prototype production batch. These tests fulfil the requirements of design qualification testing as specified in this International Standard, depending upon the specific type of cylinder design under consideration.

C.3 Cylinder type approval

C.3.1 Following an application for cylinder type approval, the regulatory authority or the independent inspection authority:

- examines the technical documentation to verify that the cylinder has been manufactured in conformity with the technical documentation and that the design is in accordance with the relevant provisions of this International Standard;
- agrees with the applicant the facility at which to carry out the examinations and tests;
- performs or cause to be performed the examinations and tests specified to determine that this International Standard has been applied, and that the procedures adopted by the manufacturer meet the requirements of this International Standard;

C.3.2 When the cylinder type meets the requirements of this International Standard, the regulatory authority issues an approval certificate to the applicant. The certificate contains the name and address of the manufacturer, results and conclusions of the examination and the necessary data for identification of the approved cylinder. A list of the relevant parts of the technical documentation is annexed to the certificate and a copy kept by the regulatory authority and the manufacturer.

An identification symbol/number, which can be stamped or suitably marked on the cylinder, is specified for each manufacturer.

C.3.3 If the manufacturer is denied an ISO cylinder approval, the regulatory authority provides written detailed reasons for such denial.

C.3.4 The manufacturer is required to inform the regulatory authority that issued the cylinder approval certification, of all modifications to the approved equipment or procedures. An additional approval is to be requested where such changes affect the conformity of cylinders with the original approval, and is given in the form of an amendment to the original cylinder approval certificate.

C.3.5 Upon request, each regulatory authority communicates to any other regulatory authority the relevant information concerning each ISO cylinder approval, approved modifications and withdrawn approvals.

C.4 Reports and certificates

C.4.1 General

The cylinder manufacturer maintains the approval certificates, and a file of technical documentation. This report complies with this annex and is signed by the manufacturer's authorized representative. The report is to be retained for not less than 15 years or the intended life of the cylinder.

Upon request, the cylinder manufacturer provides the cylinder purchaser with not less than the information requested in Form 1 of annex E.

C.4.2 Manufacturer's approval certificate

The manufacturer's approval certificate includes the following data, in addition to the test data for the relevant design approval requirements:

- a) design drawings and calculations;
- b) identification of cylinder material and certificate of analysis and result of any non-destructive testing covering the material batches from which the particular cylinders were made;
- c) result of mechanical, chemical or non-destructive tests of the cylinder or the liner, and of any over-wrap;
- d) water capacity of each cylinder in litres (l);
- e) results of the pressure tests indicating (if applicable) that the volumetric expansion recorded for the cylinder is below the stated maximum permitted;
- f) minimum design and actual thickness of cylinder, or liner and over-wrap;
- g) actual tare mass (kg).

C.4.3 Manufacturer's report

The manufacturer's report provides not less than the information given in Form 1 of annex E.

Annex D (informative)

NDE defect size by flawed cylinder cycling

The following procedure can be used to determine the NDE defect size for type CNG-1, CNG-2 and CNG-3 designs.

- a) for type CNG-1 designs having a fatigue sensitive site in the cylindrical part, introduce external flaws on to the side wall;
- b) for type CNG-1 designs having the fatigue sensitive site outside the side wall, and for type CNG-2 and CNG-3 designs, introduce internal flaws. Internal flaws may be machined prior to the heat treatment and closing of the end of the cylinder;
- c) size these artificial defects to exceed the defect length and depth detection capability of the NDE inspection method;
- d) pressure cycle to failure three cylinders containing these artificial defects in accordance with the test method specified in A.13.

If the cylinders do not leak or rupture in less than 1 000 cycles multiplied by the specified service life in years, then the allowable defect size for NDE is equal to or less than the artificial flaw size at that location.

Annex E **(informative)**

Report forms

E.1 General

This annex provides guidance on the range of information to be included in the file of technical documentation associated with cylinder approval. Examples of suitable formats are provided for Form 1 and Form 7. Forms 2 to 6 should be developed by the manufacturer to fully identify the cylinders and requirements. Each report should be signed by the independent inspection authority and the manufacturer.

E.2 List of forms

The documentation should include the following forms.

- Form 1) Report of Manufacture and Certificate of Conformance — to be clear and legible. An example of a suitable format is given in Figure E.1.
- Form 2) Report of Chemical Analysis of Material for Metallic Cylinders, Liners or Bosses — to include essential elements, identification, etc.
- Form 3) Report of Mechanical Properties of Material for Metallic Cylinders and Liners — to report all tests required by this International Standard.
- Form 4) Report of Physical and Mechanical Properties of Materials for Non-Metallic Liners — to report all tests and information required in this International Standard.
- Form 5) Report of Composite Analysis — to report all tests and data required in this International Standard.
- Form 6) Report of Hydrostatic Tests, Periodic Pressure Cycling and Burst Tests — to report test and data required in this International Standard.
- Form 7) Type Approval Certificate — an example of a suitable format is given in Figure E.2.

Manufactured by: _____

Located at: _____

Regulatory registration number: _____

Manufacturer's mark and number: _____

Serial number: _____ to _____ inclusive

Cylinder description: _____

SIZE: Outside diameter _____ mm; Length _____ mm

Marks stamped on shoulder or on labels of the cylinder are:

a) "CNG ONLY": _____

b) "DO NOT USE AFTER": _____

c) Manufacturer's mark: _____

d) Serial or part number: _____

e) Working pressure in bar: _____ bar

f) ISO Standard: _____

g) Fire protection: _____ Type

h) Date of original test (month and year): _____ - _____

i) Tare mass of empty cylinder: _____ Kg

j) Authorized body or Inspector's mark: _____

k) Water capacity in litres (l): _____

l) Test pressure in bar: _____

m) Any special instructions: _____

Each cylinder was made in compliance with all requirements of ISO Standard _____ and in accordance with the cylinder description above. Required reports of test results are attached.

I hereby certify that all these test results proved satisfactory in every way and are in compliance with the ISO standard requirements for the ISO type listed above _____

Comments: _____

Authorized body or inspection agency: _____

Inspector's signature: _____

Manufacturer's signature: _____

Place _____ Date _____

Figure E.1 — Example format for Form 1: Report of Manufacture and Certification of Conformance

TYPE APPROVAL CERTIFICATE

Issued by:
(Authorized inspection authority)

.....

applying ISO Standard.....

Concerning

.....

(TYPE OF CYLINDER)

Approval No. Date

Type of cylinder:.....
(Description of the family of cylinders (Drawing No.) which has received type approval)

Service pressure: bar

Manufacturer or agent
(Name and address of manufacturer or agent)

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

.....

Date Place

.....

(Signature of Inspector)

Figure E.2 — Example format for Form 7: Type approval certificate

Annex F **(informative)**

Environmental test

F.1 General

This optional test is applicable to types CNG-2, CNG-3, and CNG-4 cylinders only.

F.2 Cylinder set-up and preparation

Two cylinders are tested in a condition representative of installed geometry including coating (if applicable), brackets and gaskets, and pressure fittings using the same sealing configuration (i.e. O-rings) as that used in service. Brackets may be painted or coated prior to installation in the immersion test if they are painted or coated prior to vehicle installation.

The cylinders are subjected to preconditioning in accordance with F.3 and then exposed to a sequence of environments, pressures and temperatures in accordance with F.5.

Although preconditioning and fluid exposure is performed on the cylindrical section of the cylinder, all of the cylinder, including the domed sections, should be as resistant to the exposure environments as are the exposed areas.

As an alternative, a single cylinder approach may be used in which both the immersion environment and other fluids exposure tests are carried out on one cylinder. In this case, care should be taken to prevent cross contamination among the fluids.

F.3 Preconditioning

F.3.1 Preconditioning apparatus

The following types of apparatus are needed for preconditioning the test cylinder by pendulum and gravel impact.

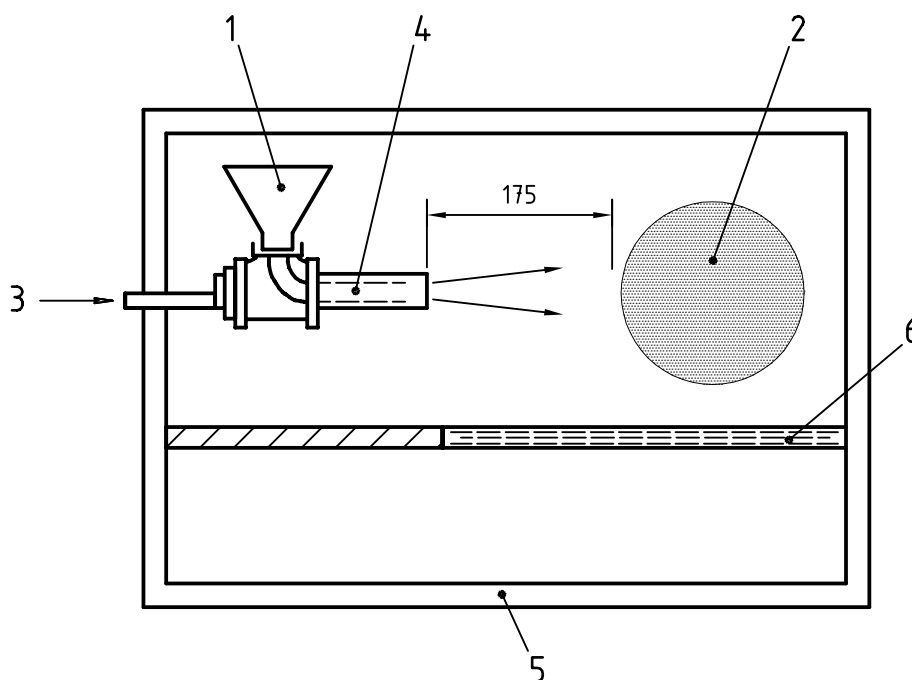
a) Pendulum impact apparatus, comprising:

- an impact body of steel having the shape of a pyramid with equilateral triangle faces and a square base, the summit and the edges being rounded to a radius of 3 mm;
- a pendulum, the centre of percussion of which coincides with the centre of gravity of the pyramid; its distance from the axis of rotation of the pendulum being 1 m and the total mass of the pendulum referred to its centre of percussion being 15 kg;
- a means of determining that the energy of the pendulum at the moment of impact is not less than 30 N·m and is as close to that value as possible;
- a means of holding the cylinder in position during impact by the end bosses or by the intended mounting brackets.

b) Gravel impact machine, comprising:

- an impact machine, constructed according to the design specifications shown in Figure F.1 and capable of being operated in accordance with ASTM D3170-87 except that the cylinder may be at ambient temperature during gravel impact;
- gravel, comprising alluvial road gravel passing through a 16 mm space screen but retained on a 9,5 mm space screen. Each application is to consist of 550 ml of graded gravel (approximately 250 to 300 stones).

Dimensions in millimetres

**Key**

- 1 Funnel
- 2 Fuel container
- 3 Air inlet
- 4 50 mm pipe
- 5 Cabinet approximately 500 mm wide
- 6 Sizing screen

Figure F.1 — Gravel impact machine**F.3.2 Preconditioning procedure****F.3.2.1 Preconditioning for the immersion environment test**

Preconditioning by both pendulum impact and gravel impact is required for the portion of the container to be used for the "immersion environment" test (see F.4.1).

With the cylinder unpressurized, precondition the central section of the cylinder that will be submerged, by an impact of the pendulum body at three locations spaced approximately 150 mm apart. Following impact, precondition each of the three locations by gravel impact application.

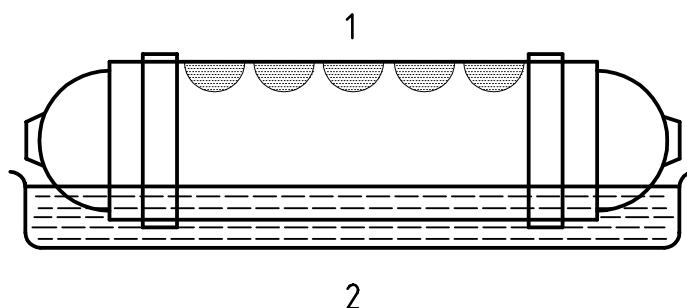
Additionally, precondition a location within the submerged portion of each domed section and 50 mm (measured axially) from the tangent by a single impact of the pendulum body.

F.3.2.2 Preconditioning for the other fluid exposure test

Preconditioning by gravel impact only is required for the portion of the container to be used for the “other fluid exposure” test (see F.4.2)

Divide the upper section of the cylinder used for the “other fluids exposure” test into 5 distinct areas of nominal diameter 100 mm and mark these for preconditioning and fluid exposure (see Figure F.2). Ensure that the areas do not overlap on the cylinder surface and, for the single cylinder approach, do not overlap the immersed section of the cylinder. While convenient for testing, the areas need not be oriented along a single line.

With the cylinder unpressurized, precondition each of the 5 areas identified in Figure F.2 for other fluid exposure on the cylinder by gravel impact application.



Key

- 1 Other fluid exposure area
- 2 Immersion area (lower third)

Figure F.2 — Cylinder orientation and layout of exposure areas

F.4 Environments

F.4.1 Immersion environment

At the appropriate stages in the test sequence (see Table F.1) orient the cylinder horizontally to immerse the lower third of the cylinder diameter in a simulated acid rain/road salt water solution composed of the following compounds:

- deionized water;
- sodium chloride: 2,5 % (mass fraction) $\pm$ 0,1 %;
- calcium chloride: 2,5 % (mass fraction) $\pm$ 0,1 %;
- sulfuric acid: sufficient to achieve a solution pH of $4,0 \pm 0,2$.

Adjust the solution level and pH prior to each test step which uses this liquid.

Maintain the temperature of the bath at $21\text{ }^{\circ}\text{C} \pm 5\text{ }^{\circ}\text{C}$. During immersion, hold the unsubmerged section of the cylinder in ambient air.

F.4.2 Other fluid exposure

At the appropriate stages in test sequence (see Table F.1) expose each marked area to one of five solutions for 30 min. Use the same environment for each location throughout the test. The solutions are:

- sulfuric acid: 19 % (volume fraction) aqueous solution;
- sodium hydroxide: 25 % (mass fraction) aqueous solution;
- methanol/gasoline: 30/70 % concentrations;
- ammonium nitrate: 28 % (mass fraction) aqueous solution.
- windscreen washer fluid.

During the exposure, orient the test cylinder with the exposure area uppermost. Place a pad of glass wool one layer thick (approximately 0,5 mm) and trimmed to the appropriate dimensions on the exposure area. Using a pipette, apply 5 ml of the test fluid to the glass wool. Ensure that the pad is wetted evenly across its surface and through its thickness. Pressurize the cylinder and remove the gauze pad after pressurization for 30 min.

F.5 Test conditions

F.5.1 Pressure cycle

At the appropriate stage in the test sequence (see Table F.1), subject the cylinder to hydraulic pressure cycles of between 20 bar and 260 bar for the ambient and high temperature steps, and between 20 bar and 160 bar for the lower temperature steps. Hold the maximum pressure for a minimum of 60 s and ensure that each full cycle takes no less than 66 s.

F.5.2 High and low temperature exposure.

At the appropriate stages in the test sequence (see Table F.1), bring the surface of the cylinder to a high or low temperature in air. The low temperature shall be no higher than $-35\text{ }^{\circ}\text{C}$ and the high temperature shall be $82\text{ }^{\circ}\text{C} \pm 5\text{ }^{\circ}\text{C}$ as measured on the surface of the cylinder.

F.6 Test procedure

The test procedure is as follows:

- a) precondition the cylinders (or cylinder in the single cylinder approach) in accordance with F.3.2;
- b) carry out the sequences of environmental exposure, pressure cycling and temperature exposure as defined in Table F.1; do not wash or wipe the cylinder surface between stages;
- c) following completion of the sequences, subject the cylinders (or cylinder) to a hydrostatic pressure burst test to destruction in accordance with A.12.

F.7 Acceptable results

The test is considered to be satisfied if the burst pressure of the cylinders (or cylinder) is no less than 1,8 times the service pressure.

Table F.1 — Test conditions and sequence

Test steps			Environments	Number of pressure cycles	Temperature
Two cylinder approach		Single cylinder approach			
Immersion cylinder	Other Fluids	Alternative single cylinder			
—	1	1	Other fluids (40 min)	—	Ambient
1	—	2	Immersion	500 × service life (years)	Ambient
—	2	—	Air	500 × service life (years)	Ambient
—	3	3	Other Fluids (40 min)	—	Ambient
2	4	4	Air	250 × service life (years)	Low
—	5	5	Other Fluids (40 min)	—	Ambient
3	6	6	Air	250 × service life (years)	High

Annex G (informative)

Verification of stress ratios using strain gauges

This annex describes a procedure that may be used to verify stress ratios by use of strain gauges.

- a) The stress-strain relationship for fibres is always elastic, therefore, stress ratios and strain ratios are equal.
- b) High elongation strain gauges are required.
- c) Strain gauges should be orientated in the direction of the fibres on which they are mounted (i.e. with hoop fibre on the outside of the cylinder, mount gauges in the hoop direction).
- d) **Method 1** (applies to cylinders that do not use high tension winding)
 - 1) Prior to autofrettage, apply strain gauges and calibrate.
 - 2) Measure strains at autofrettage, at zero pressure after autofrettage and at working and minimum burst pressure.
 - 3) Confirm that the strain at burst pressure divided by the strain at working pressure meets the stress ratio requirements. For hybrid construction, the strain at operating pressure is compared with the rupture strain of cylinders reinforced with a single fibre type.
- e) **Method 2** (applies to all cylinders)
 - 1) At zero pressure after winding and autofrettage, apply strain gauges and calibrate.
 - 2) Measure strains at zero, working and minimum burst pressures.
 - 3) At zero pressure, after strain measurements have been taken at the working and minimum burst pressures, and with strain gauges monitored, cut the cylinder section apart so that the region containing the strain gauge is approximately 125 mm long. Remove the liner without damaging the composite. Measure the strains after the liner is removed.
 - 4) Adjust the strain readings at zero, operating, and minimum burst pressures by the amount of strain measured at zero pressure with and without the liner.
 - 5) Confirm that the strain at burst pressure divided by strain at working pressure meets the stress ratio requirements. For hybrid construction, the strain at operating pressure is compared with the rupture strain of cylinders reinforced with a single fibre type.

Annex H (informative)

Manufacturer's instructions for handling, use and inspection of cylinders

H.1 General

The primary function of the manufacturer's instructions is to provide guidance to the cylinder purchaser, distributor, installer and user for the safe use of the cylinder over its intended service life.

H.2 Distribution

The manufacturer should advise the purchaser to supply these instructions to all parties involved in the distribution, handling, installation and use of the cylinders.

The document may be reproduced to provide sufficient copies for this purpose; however, it should be marked to provide reference to the cylinders being delivered.

H.3 Reference to existing codes, standards and regulations

Specific instructions may be stated by reference to national or recognized codes, standards and regulations.

H.4 Cylinder handling

Handling procedures should be described which would ensure that the cylinders will not suffer unacceptable damage or contamination during handling.

H.5 Installation

Installation instructions should be provided which would ensure that the cylinders do not suffer unacceptable damage during installation and during normal operation over the intended service life.

Where the mounting is specified by the manufacturer, the instructions should, where relevant, contain details such as mounting design, the use of resilient gasket materials, the correct tightening torques and avoidance of direct exposure of the cylinder to the environment, chemicals and mechanical contacts. Cylinder locations and mountings should comply with recognized installation standards.

Where the mounting is not specified by the manufacturer, the manufacturer should draw the purchaser's attention to possible long-term impacts of the vehicle mounting system, e.g., vehicle body movements and cylinder expansion/contraction under the pressure and temperature conditions of service.

Where applicable, the purchaser's attention should be drawn to the need to provide installations such that liquids or solids cannot be collected to cause cylinder material damage.

The correct pressure relieve device to be fitted should be specified.

Cylinder valves, pressure relief devices and connections should be protected against breakage in a collision. If this protection is mounted on the cylinder, the design and method of attachment should be approved by the cylinder

manufacturer. Factors to be considered include the ability of the cylinder to support any transferred impact loads and the effect of localized strains on cylinder stresses and fatigue life.

H.6 Use of cylinders

The manufacturer should draw the purchaser's attention to the intended service conditions specified in this International Standard, in particular the cylinder's permissible number of pressure cycles, its life in years, the gas quality limits and the permissible maximum pressures.

H.7 In-service inspection

The manufacturer should clearly specify the user's obligation to observe the required cylinder inspection requirements (e.g. reinspection interval, by authorized personnel). This information should be in agreement with the design approval requirements, and should cover the following aspects.

a) Periodic requalification

Inspection and/or testing is required to be performed in accordance with the relevant regulations of the country(ies) where the cylinders are used.

Recommendations for periodic requalification by visual inspection or testing during the service life should be provided by the cylinder manufacturer on the basis of use under service conditions specified herein. Each cylinder should be visually inspected at least every 36 months, and at the time of any re-installation, for external damage and deterioration, including under the support straps. The visual inspection should be performed by a competent agency approved or recognized by the regulatory authority, in accordance with the manufacturer's specifications.

Cylinders without labels or stamps containing mandatory information, or with labels or stamps containing mandatory information that is illegible in any way should be removed from service. If the cylinder can be positively identified by manufacturer and serial number a replacement label or stamping may be applied, allowing the cylinder to remain in service.

b) Cylinders involved in collisions

Cylinders which have been involved in a vehicle collision should be re-inspected by an authorized inspection agency. Cylinders which have not experienced any impact damage from the collision may be returned to service, otherwise the cylinder should be returned to the manufacturer for evaluation.

c) Cylinders involved in fires

Cylinders which have been subject to the action of fire should be re-inspected by an authorized inspection agency, or condemned and removed from service.

