
**Gas cylinders — Refillable
permanently mounted composite
tubes for transportation**

*Bouteilles à gaz — Tubes composites rechargeables montés de façon
permanente pour le transport*

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Foreword

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

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

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

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

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

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

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document provides a specification for the design, manufacture and initial inspection and testing of composite tubes permanently mounted in a transport frame for worldwide usage. Current standards, such as ISO 11515 and ISO 11119, do not address the interaction between the tubes and the transport frame.

This document aims to eliminate existing concerns about duplicate inspection and restrictions because of the lack of International Standards and should not be construed as reflecting on the suitability of the practice of any nation or region.

This document has been written so that it is suitable to be referenced in the UN Model Regulations^[6].

This document addresses tubes of larger volume than previous documents.

This document is not applicable to on-board fuel cylinders in natural gas vehicles.

[Annexes B](#) to [F](#) are informative. [Annex A](#) is normative.

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Gas cylinders — Refillable permanently mounted composite tubes for transportation

1 Scope

This document specifies the minimum requirements for the material, design construction and workmanship, manufacturing processes, examination and testing at time of manufacture of an assembly of permanently mounted composite tube(s) in a frame with associated components.

Tubes covered by the requirements of this document are:

- a) of composite construction, permanently mounted in a transport frame and suitable for specified service conditions, designated as:
 - 1) Type 3 — a fully wrapped tube with a seamless metallic liner and composite reinforcement on both the cylindrical part and the dome ends; or
 - 2) Type 4 — a fully wrapped tube with a non-load sharing liner and composite reinforcement on both the cylindrical part and the dome ends.
- b) with water capacities from 450 l up to and including 10 000 l;
- c) containing compressed gases but excluding:
 - 1) liquefied gases,
 - 2) dissolved gases, and
 - 3) gases and gas mixtures which are classified for transport as toxic or oxidizing;
- d) with working pressure up to 1 000 bar.

This document does not address tubes with working pressure times water capacity ($p \times V$) more than 3 000 000 bar·l.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

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

ISO 1496-3:1995, *Series 1 freight containers — Specification and testing — Part 3: Tank containers for liquids, gases and pressurized dry bulk*

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

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

ISO 7866:2012, *Gas cylinders — Refillable seamless aluminium alloy gas cylinders — Design, construction and testing*

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

ISO/TS 17519:2019(E)

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

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

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

ISO 10156, *Gas cylinders — Gases and gas mixtures — Determination of fire potential and oxidizing ability for the selection of cylinder valve outlets*

ISO 10286, *Gas cylinders — Terminology*

ISO 10298, *Gas cylinders — Gases and gas mixtures — Determination of toxicity for the selection of cylinder valve outlets*

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

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

ISO 11120:2015, *Gas cylinders — Refillable seamless steel tubes of water capacity between 150 l and 3000 l — Design, construction and testing*

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

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

ISO 13769, *Gas cylinders — Stamp marking*

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

ISO 14456, *Gas cylinders — Gas properties and associated classification (FTSC) codes*

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

ASTM D1308, *Standard Test Method for Effect of Household Chemicals on Clear and Pigmented Organic Finishes*

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

ASTM D3170, *Standard Test Method for Chipping Resistance of Coatings*

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

ASTM D4814, *Standard Specification for Automotive Spark-Ignition Engine Fuel*

ASTM G154, *Standard Practice for Operating Fluorescent Light Apparatus for UV Exposure of Nonmetallic Materials*

NACE/TM 0177-2016¹⁾, *Laboratory Testing of Metals for Resistance to Sulfide Stress Cracking and Stress Corrosion Cracking in H₂S Environments*

INTERNATIONAL MARITIME ORGANIZATION. *International Convention for Safe Containers, 1972*

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

3 Terms and definitions

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

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

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

3.1

autofrettage

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

3.2

autofrettage pressure

pressure within the over-wrapped tube at which the required distribution of stresses between the liner and the over-wrap is established

3.3

composite tube

tube made of resin-impregnated continuous filament wound over liner

3.4

finished tubes

completed tubes 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

3.5

liner

inner portion of a composite tube, comprising a metallic (seamless) or non-metallic (seamless or welded) vessel, whose purpose is both to contain the gas and transmit the gas pressure to the composite overwrap

3.6

overwrap

reinforcement system of filament and resin applied over the liner

3.7

test pressure

required pressure applied during a pressure test

3.8

working pressure

settled pressure at uniform temperature of 15 °C

3.9

oxidizing gas

gas containing more than the equivalent of 30 bar partial pressure of oxygen

Note 1 to entry: See ISO 14456.

3.10

non-load sharing liner

non-metallic liner that has a burst pressure less than 5 % of the nominal burst pressure of the finished composite tube

**3.11
load sharing liner**

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

**3.12
permanently mounted composite tubes**

tubes mounted in an ISO frame or tube trailer for transportation as a unit, such that tools are required to remove them, and not intended to be transported or used outside of the ISO frame or tube trailer

**3.13
settled pressure**

pressure of the contents of a pressure receptacle in thermal and diffusive equilibrium

**3.14
polymer**

large, chain-like molecule made up of monomers, which are small molecules, and can be naturally occurring or synthetic

Note 1 to entry: For use in this document, includes polymer mixtures, additives, plastics, and other non-metallic materials suitable for use as a non-load sharing liner.

4 Basis for the design requirements

4.1 General

WARNING — The combination of pressure and volume up to 3 000 000 bar·l represents a substantial amount of energy that has to be taken into consideration with regard to the intended service (e.g. safety distances to be established in case of an incident).

The requirements specified in this clause are provided as the basis for the design, manufacture, inspection, testing and approval of tubes that are to be permanently mounted in a frame and used to transport gases at ambient temperatures. The requirements do not include vacuum service.

4.2 Design life

Design life shall be specified by the manufacturer and demonstrated by design prototype testing. The minimum design life shall be 15 years and the maximum design life shall be 30 years, except that the maximum design life for Type 3 tubes with carbon steel liners shall be 20 years.

4.3 Design number of filling cycles

Tubes shall be designed to be filled 750 times per year of design life.

4.4 Temperature range

4.4.1 Gas temperature

Tubes shall be designed to have a settled gas temperature of not less than $-40\text{ }^{\circ}\text{C}$ and not more than $+65\text{ }^{\circ}\text{C}$.

NOTE Developed gas temperatures in the tubes during filling and discharge can vary beyond these limits.

4.4.2 Tube material temperature

Tubes shall be designed to be suitable for external exposure to temperatures from $-40\text{ }^{\circ}\text{C}$ to $82\text{ }^{\circ}\text{C}$.

Temperatures over $+65\text{ }^{\circ}\text{C}$ shall be sufficiently local, or of short duration, such that the bulk temperature of gas in the tube does not exceed $+65\text{ }^{\circ}\text{C}$.

4.5 Gas compatibility

Compatibility of the liner shall be demonstrated for the intended content for all pressure and temperature ranges (e.g. by reference to ISO 11114-1, ISO 11114-2, reference to current use, or verification of key properties following exposure).

Type 3 tubes with steel liners shall not carry CNG for which the chemical composition is not in accordance with ISO 11439:2013, 4.5.

NOTE See ISO 11120:2015, Clause 12 for additional guidance on requirements for embrittling gases.

4.6 Prohibited gases

The tubes shall not be filled with oxidizing gas, with toxic gases, or with dissolved or liquified gases as specified in ISO 10156, ISO 10298 and ISO 14456.

4.7 External environment

General compatibility with environmental fluids shall be demonstrated by conducting testing as specified in [A.8](#).

5 Conformity

5.1 General

To ensure that the tubes conform to the requirements of this document, they shall be subject to inspection and testing in accordance with [Clauses 5, 6, and 7](#).

Equipment used for measurement, testing and examination during production shall be maintained and calibrated.

5.2 Design documentation

5.2.1 General

Type approval consists of:

- a) Tube design approval, comprising submissions of information by the manufacturer to the inspector, as detailed in [5.2.2](#).
- b) Prototype testing of the tube, in accordance with [Annex A](#), comprising testing carried out under the supervision of the inspector. The tube material, design, manufacture and examination shall be shown to be satisfactory for the intended service by meeting the requirements of [6.5](#).
- c) Frame design approval, comprising submissions of information by the manufacturer to the inspector, as detailed in [5.2.3.3](#).
- d) Prototype testing for the mounting frame. The mounting frame material, design, manufacture and examination shall be proved to be adequate for its intended service by meeting the requirements of [Clause 9](#).

The test data shall also document the dimensions and weights of each of the test tubes.

5.2.2 Tube design verification

Design verification shall include a review of the:

- a) statement of service, in accordance with the requirements of [5.2.3.1](#);

- b) design data, in accordance with the requirements of [5.2.3.2](#), [5.2.3.3](#), [5.2.3.4](#), and [5.2.3.5](#);
- c) fire protection, in accordance with the requirements of [5.2.4](#)

provided by the manufacturer who can then request the inspector to provide a design conformance report.

The title, reference number, revision number and dates of original issue and version issues of each document shall be given.

5.2.3 Statement of design intent

NOTE The purpose of this design statement is to provide guidance to the installers of tubes and users.

5.2.3.1 Statement of service

The statement of service shall include:

- a) a statement that the tube design is suitable for use in the service conditions defined in [Clause 4](#) for the service life of the tube;
- b) a statement of the design life;
- c) a specification for fire protection, such as the pressure relief devices, and insulation if provided;
- d) a specification for the support methods (i.e. boss or strap mount) and protective coatings if applicable;
- e) a description of the tube design;
- f) a description of the filling/emptying interfaces (e.g. threaded interfaces), with specifications as required;
- g) a reference to operational controls required for filling and emptying;
- h) a statement of the impact resistance level.

5.2.3.2 Tube drawings

Drawings and supporting documents shall include at least:

- a) a title, reference number, date of issue, and revision numbers with dates of issue if applicable;
- b) a reference to this document (ISO/TS 17519:2019);
- c) all dimensions and tolerances, including key subcomponents (e.g. liners and bosses);
- d) mass, complete with tolerance of finished tubes;
- e) all material specifications, including fibres, resins, and key subcomponents (e.g. bosses, liner), complete with minimum mechanical or tolerance ranges, and heat treatment;
- f) method of manufacture for subcomponents and overwrap, including key process specifications, the number and type of strands used in the winding band, number of layers, and layer orientation;
- g) test pressure and working pressure of the tube, and minimum burst pressure of the liner for Type 3 tubes;
- h) autofrettage pressure and approximate duration (if applicable);
- i) maximum developed pressure at 65 °C for specific gas to be transported (if applicable);
- j) details of the fire protection system and of any exterior protective coating;

- k) the design life in years (minimum 15 years and maximum 30 years);
- l) manufacturer's recommended time in the fire if a thermally activated pressure relief device (PRD) is not used (based on time to burst during qualification testing, see [A.9.6](#) for acceptable results and minimum time);
- m) port details including thread form, sealing method, seal specification (O-ring specification if used), and installation instructions;
- n) water volume of finished tube with a stated acceptance tolerance;
- o) list of intended contents if intended for dedicated gas service;
- p) other data required for safe operational use.

5.2.3.3 Frame drawings

Drawings shall include at least:

- a) a title, reference number, date of issue, and revision numbers with dates of issue if applicable;
- b) a reference to this document (ISO/TS 17519:2019);
- c) all dimensions and tolerances;
- d) mass, complete with tolerance of finished frames;
- e) material specifications, complete with minimum mechanical properties or tolerance ranges;
- f) other data required for safe operational use.

5.2.3.4 Stress analysis report

A stress analysis shall be carried out so as to demonstrate that the tube meets the requirements of [6.3.3](#).

A stress analysis shall be carried out so as to demonstrate that the frame can withstand the forces developed from the loading prescribed in [9.5](#), and shall show a safety factor as appropriate:

- for steels having a clearly defined yield point, a safety factor of 1,5 in relation to minimum yield strength;
- for steels with no clearly defined yield point, a safety factor of 1,5 in relation to the minimum 0,2 % offset yield strength;
- for austenitic steels, a safety factor of 1,5 in relation to the 1 % offset yield strength;
- for materials other than steel, design practices shall ensure a level of safety equivalent to those established for steel.

A table summarizing the calculated stresses shall be provided.

5.2.3.5 Material property data

A detailed description of the materials and material properties (with tolerances) used in the preparation of the stress analysis report, including any modification of material properties caused by the tube fabrication processes (e.g. heat treatment specification if applicable), including the hardness of the metallic liner, shall be provided.

Test data from samples manufactured by filament winding (or an equivalent process, to be described) shall be provided and shall at least include:

- a) glass transition temperature in case of thermoset resin (ASTM D3418);

- b) interlaminar shear strength of the cured composite material (ISO 14130); and
- c) the suitability of the materials for service under the conditions specified in [Clause 4](#).

5.2.4 Fire protection

The arrangement of the pressure relief and fire detection systems, and/or insulation if provided, that protects the tube from sudden rupture when it is exposed to the tests described in [A.9](#), shall be specified. To pass the test, the tube shall meet the requirements of [A.9.6](#).

5.2.5 Tube specification sheet

A summary of the documents providing the information required in [5.2.2](#) shall be listed on a specification sheet for each tube design.

5.3 Type approval

An example of a type approval document is given in the [Annex B](#).

5.4 Assembly documentation

The assembler permanently mounting the tube in the frame, the frame manufacturer and the tube manufacturer can be separate companies. When more than one company is involved, responsibility for the final product shall be agreed between the parties involved.

Where tubes are transported to the frame manufacturer or assembler, precautions shall be taken to avoid any external impact on the tube. If it is suspected or known that the tube has had an external impact, it shall be inspected prior to assembly so as to ensure that its in-service use has not been compromised.

6 Tube requirements

6.1 Failure modes

The tube shall be designed to meet the requirements described in [A.1](#) and [A.7](#), thereby demonstrating either a “leakage-before-break” failure mode or the ability to cycle to test pressure a total of 3 times the expected number of pressure cycles to be seen during the lifetime of the tube.

6.2 Materials

Materials used shall meet the service conditions specified in [Clause 4](#). The design shall ensure that incompatible materials do not come in contact with each other.

6.2.1 Liner materials

6.2.1.1 Metal liners

Seamless steel liners shall conform to the chemical composition, heat treatment, tensile test, and impact test requirements of ISO 9809-1, ISO 9809-2, ISO 9809-3 or ISO 11120, as appropriate for the steel used, and shall meet the requirements of [A.20](#), and [A.21](#).

Seamless aluminium alloy liners shall conform to the requirements of ISO 7866 for chemical composition, thermal treatment, tensile test, corrosion resistance (ISO 7866:2012, Annex A), and sustained load cracking resistance (ISO 7866:2012, Annex B).

Liner burst pressure shall not be more than 30 % of the minimum design burst pressure of the finished tube.

6.2.1.2 Polymer liners

The polymeric material shall be compatible with the service conditions specified in [Clause 4](#) and the relevant requirements of ISO 11114-2.

6.2.2 Composite materials

6.2.2.1 Resins

Thermosetting or thermoplastic resins may be used. Examples of suitable matrix materials are epoxy, modified epoxy, polyester and vinyl-ester, polyurethane thermosetting resin and polyethylene, polypropylene and polyamide thermoplastic.

The glass transition temperature of a thermosetting resin material used shall be determined in accordance with the requirements of ASTM D3418 and checked against the test requirements in [6.5.2.9](#). The Vicat softening point of a thermoplastic resin material used shall be determined in accordance with the requirements of ISO 306.

6.2.2.2 Fibres

The structural reinforcing filament materials to be used shall be glass fibre, aramid fibre or carbon fibre or a combination of these fibres. If carbon fibre reinforcement is used, the design shall address the prevention of galvanic corrosion when it is in contact with metallic components of the tube.

The tube manufacturer shall retain:

- a) specifications for composite materials;
- b) the material manufacturer's recommendations for storage, conditions and shelf life; and
- c) the fibre manufacturer's written confirmation that each shipment conforms to the specification requirements.

6.2.3 Metal end bosses

The metal end bosses connected to the liner shall be of a material compatible with the service conditions specified in [Clause 4](#) and meet the relevant requirements of ISO 11114-1.

6.3 Design requirements

6.3.1 Test pressure

Test pressure shall be 1,5 times working pressure.

6.3.2 Burst pressure and fibre stress ratios

The composite over-wrap shall be designed for high reliability under sustained loading and cyclic loading and these requirements shall be achieved by meeting or exceeding the composite reinforcement stress ratio values given in [Table 1](#).

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 minimum design burst pressure of the tube divided by the working pressure.

The tube manufacturer may choose to use the reference burst ratio in place of the minimum stress ratios. In that case, the minimum burst ratio requirements shown in [Table 1](#) shall apply in place of the stress ratios. Verification, either by analysis or test, of the stress ratio used is required for each tube design.

NOTE 1 For Type 3 tubes, the stress ratio is generally not linear with pressure and is not the same as the burst ratio. The nonlinear behaviour is due to the yielding of the metallic liner during autofrettage and during subsequent burst testing. The nonlinear behaviour is affected by the liner and composite thickness and modulus of elasticity, by liner plastic behaviour and by autofrettage pressure.

When analysing tubes with hybrid reinforcement (two or more different fibres), calculation of the load share between the different fibres is based on the different elastic moduli and cross-sectional area of the fibres, e.g. calculate strains based on fibre areas and modulus, and from the resulting strain, and the modulus for each fibre, calculate the stress in the fibre.

NOTE 2 Confirmation with strain gages is possible.

The strength of individual types of fibres used in hybrid construction may be verified by testing of containers reinforced with a single type of fibre. In a hybrid construction, the applicable stress ratio requirements shall be met in one of the two following ways.

- a) If load sharing between the various fibre reinforcing materials is considered a fundamental part of the design, each fibre shall meet the stated stress ratios.
- b) If load sharing between fibres is not considered as a fundamental part of the design, then one of the reinforcing fibres shall be capable of meeting the stress ratio requirements even if all other fibre reinforcing materials are removed.

Table 1 — Minimum burst ratios and stress ratios for tubes

Fibre type	Minimum stress ratio	Minimum burst ratio
Glass	3,65	3,65
Aramid	3,10	3,10
Carbon	2,35	2,35

6.3.3 Stress analysis

A stress analysis shall be performed.

The stress analysis shall use suitable techniques to be able to establish the stress distribution throughout the tube. For Type 3 designs, the analysis shall take account of nonlinear material behaviour of the liner including manufacturing induced stresses (e.g. due to wind tension and autofrettage).

The pressures used in the stress analysis shall be working pressure, test pressure and design burst pressure. For Type 3 tubes the stress analysis shall also take account of the autofrettage pressure and zero pressure after autofrettage.

NOTE [Annex C](#) gives examples of how the stress ratios can be verified using strain gauges.

The requirements shown in [Table 1](#) shall be met.

6.3.4 Openings

Openings are only allowed in the end bosses or necks of liners, not through the composite laminate. End bosses or necks of liners are only allowed on the longitudinal axis of the tube.

6.3.5 Fire protection

A bonfire test is required for all tube assemblies.

A fire protection system shall be provided, and it shall meet the requirements of [A.9](#). A fire protection system either allows gas to escape from the tube(s) to prevent rupture, and/or provides insulation or shielding such that the tube assembly will not rupture within 20 min. A fire protection system that allows gas to escape shall be thermally activated, and not pressure activated.

6.3.6 Flammable gas permeation

If the tube is used for flammable gases, an assessment and/or test shall be prepared to evaluate the effects of permeation to ensure that combustible mixtures will not be developed in the frame, with consideration for gases, their flammability limits, and ventilation level of the frame area.

6.4 Construction and workmanship

6.4.1 General

The tube shall be manufactured from a liner over-wrapped with continuous filament windings. The fibres shall be applied under controlled tension during winding.

6.4.2 Liner and boss requirements

Liners and bosses shall meet the requirements of [5.2.3.2](#), [5.2.3.4](#), [5.2.3.5](#), and [6.1](#), [6.2](#) and [6.3](#).

6.4.3 Fibre winding

Winding shall be applied under controlled conditions and meet the design requirements of [5.2.3](#).

If tubes are subjected to pre-stressing or fibre tensioning during winding (e.g. to actively change the final stresses in the finished tube), pressure in the tube and fibre tension during winding shall be recorded.

6.4.4 Curing of resins

After winding is completed the composite shall be cured (if appropriate) using a controlled temperature profile as specified in the fabrication documents. The maximum curing temperature shall be such that the mechanical properties of all the materials in the composite tube shall not be affected.

6.4.5 Neck threads

Internal and external neck threads shall meet the requirements of the design specification by means of gauging (e.g. to permit the use of a corresponding valve thus minimizing neck stresses following the valve torquing operation). Care shall be taken to ensure that neck threads are accurately cut, are of full form and free from any sharp profiles (e.g. burrs).

6.4.6 Autofrettage

If tubes are subjected to an autofrettage operation, the autofrettage pressure and duration shall be as specified in [5.2.3](#). Autofrettage pressure shall not deviate from the manufacturer's specification by more than ± 5 %.

A change in autofrettage pressure of more than ± 5 % shall be considered to be a change of design as described in [Table 3](#).

Autofrettage, if used, shall be carried out before the hydrostatic pressure test.

The autofrettage pressure shall meet the drawing requirements of [5.2.3.2](#).

The manufacturer shall establish a procedure for verifying the selection of the autofrettage pressure used in regard to meeting stress ratio requirements.

6.4.7 Exterior environmental protection

Where a coating (e.g. a metal spray coating) is an integral part of the tube (i.e. the coating has to be applied in order for the tube to meet its design and test requirements) it shall be applied before the prototype test programme is carried out. A coating that is an integral part of the design shall meet the requirements of [A.3](#). Where a coating is not an integral part of the tube (e.g. a coating applied for appearances) it need not be applied before carrying out the prototype test programme.

6.5 Type approval procedure

6.5.1 General

Prototype testing shall be conducted on each new design using finished tubes which are representative of normal production and complete with identification marks, except where subscales are permitted. Results shall be reported. Prototype testing may be conducted using sub-scale units as noted for each prototype test. The test tubes or liners shall be selected and the prototype tests detailed in [6.5.2](#) carried out. If more tubes or liners are subjected to the tests than are required by this document, all results shall be documented.

6.5.2 Prototype tests

6.5.2.1 General

6.5.2.1.1 Tests required

The prototype tests to be carried out and the number of test objects are listed in [Table 2](#). A single test may be conducted on a single tube or liner, or, more than one test may be conducted on a single tube or liner if appropriate.

6.5.2.1.2 Full diameter sub-scale tubes

Type approval testing may be conducted with a full scale diameter tube of shorter length.

However, the L/D ratio of a sub-scale tube shall be greater than 2,5. If the full scale tube L/D ratio is less than 2,5, a full scale tube is required.

6.5.2.1.3 General sub-scale tubes

Material properties may be demonstrated using a sub-scale tube of a size appropriate to determine the appropriate properties of the laminate.

The stress levels in the sub-scale tube shall be the same as for a full scale tube.

NOTE General sub-scale tubes can be used for tests in [6.5.2.7](#), [6.5.2.9](#), and [6.5.2.10](#).

Table 2 — Required prototype tests and number of test objects

Reference	Test description	Subscale accepted ^b	Type 3 Tubes	Type 4 Tubes	Requirement
6.5.2.2.1	Material — Polymer liner			1 liner	
6.5.2.2.2	Material — Metal liners and bosses		1 liner	—	For Type 4 tubes, only related to boss material.
				Boss(es) only	
6.5.2.2.3	Material — Resin material		1 tube	1 tube	
6.5.2.3	Burst		2 tubes	2 tubes	
6.5.2.4	Ambient temperature cycle	x	2 tubes	2 tubes	At least 1 test unit shall be full scale.
6.5.2.5	Leak before burst (LBB)	x	2 tubes	2 tubes	
6.5.2.6	Bonfire		1 tube	1 tube	1 test
6.5.2.7	Environmental	x	1 tube	1 tube	
6.5.2.8	Flaw tolerance	x	1 tube	1 tube	
6.5.2.9	High temperature creep	x	1 tube	1 tube	Test required only when the glass transition temperature of the resin does not exceed 102 °C.
6.5.2.10	Accelerated stress rupture	x	1 tube	1 tube	Test required only when the tube is reinforced with glass fibre.
6.5.2.11	Extreme temperature pressure cycle	x	1 tube	1 tube	
6.5.2.12	External loading		1 frame	1 frame	
6.5.2.13	Impact ^a	x	1 tube	1 tube	
6.5.2.14	Boss torque	x		1 tube	
6.5.2.15	Permeation	x		1 tube	
6.5.2.16	Gas cycling and blow down	x		1 tube	
6.5.2.17	High velocity impact (gunfire) test	x	1 tube	1 tube	

^a Drop test is not required. The effect of external impact is included in this test and in the requirements for the frame (see [Clause 9](#)).

^b Test that can be done on subscale test specimens are marked "x" if specified condition in each test are fulfilled.

6.5.2.2 Material test for liners

6.5.2.2.1 Polymer liners

The tensile yield strength and ultimate elongation of the liner material shall be determined using five specimens which shall be tested in accordance with, and meet, the requirements of [A.14](#).

If the polymer liner has a weld joint, five additional specimens taken from the liner in the weld section shall be subjected to tensile test in accordance with the requirements of [A.14](#). Either, each specimen shall break outside of the weld joint or shall show ductility in the case of break at weld joint.

The liner softening temperature shall be determined in accordance with, and meet, the requirements of [A.15](#).

6.5.2.2.2 Metal liners and bosses

The tensile properties of the metal in the finished liner shall be determined in accordance with, and meet, the requirements of [6.2.1.1](#) and shall meet the requirements therein.

The impact properties of steel in a liner shall be determined in accordance with, and meet, the requirements of [6.2.1.1](#).

If the upper limit of the specified tensile strength of steel in a liner exceeds 950 MPa, the steel from a finished liner shall be tested in accordance with, and meet, the requirements of [A.20](#). Liner or bosses manufactured in steel having a tensile strength exceeding 950 MPa shall not be used in embrittling gas service.

Liners or metal bosses manufactured from aluminium alloys shall meet the requirements of the corrosion tests and sustained load cracking tests described in [6.2.1.1](#).

Steel liners shall have an external coating to prevent corrosion, and a representative sample of liner specimen with coating shall pass the coating requirements of [A.3](#).

6.5.2.2.3 Resin material

The glass transition temperature of the resin material shall be determined in accordance with the requirements of ASTM D 3418. Samples shall be taken from sufficient locations (e.g. inside and outside the tube and from an end dome) so as to be able to confirm that the glass transition temperature (T_g) meets the manufacturer's specification throughout the structural composite. The interlaminar shear strength of the resin material shall be determined in accordance with the requirements of [A.18](#) and the results checked for conformance to the manufacturer's design specification.

6.5.2.3 Burst test

Two tubes shall be hydraulically pressurized to failure in accordance with the requirements of [A.6](#). The tube shall meet the stress ratio and the burst ratio requirements specified in [Table 1](#).

Sub-scale tubes are not allowed.

6.5.2.4 Ambient temperature cycle test

Two tubes shall be pressure cycle tested at ambient temperature in accordance with the requirements of [A.7](#).

One sub-scale tube, as defined in [6.5.2.1.2](#), may be used in place of a full size tube for this test and in addition, at least one full size tube shall be tested.

6.5.2.5 Leak-before-break (LBB) test

Two tubes shall be tested in accordance with, and meet, the requirements of [A.1](#).

Sub-scale tubes, as defined in [6.5.2.1.2](#), may be used in place of full size tubes for these tests.

6.5.2.6 Bonfire test

One tube shall be tested in accordance with, and meet the requirements of, [A.9](#).

Sub-scale tubes are not allowed.

6.5.2.7 Environmental test

One tube shall be tested in accordance with, and meet, the requirements of [A.8](#).

A sub-scale tube, as defined in [6.5.2.1.3](#), may be used in place of a full size tube for this test.

6.5.2.8 Flaw tolerance test

One tube shall be tested in accordance with, and meet the requirements of [A.10](#).

A sub-scale tube, as defined in [6.5.2.1.2](#), may be used in place of a full size tube for this test.

6.5.2.9 High temperature creep test

In tube designs where the glass transition temperature of the resin does not exceed 102 °C, one tube shall be tested in accordance with, and meet the requirements of [A.11](#).

A sub-scale tube, as defined in [6.5.2.1.3](#), may be used in place of a full size tube for this test.

6.5.2.10 Accelerated stress rupture test

This test shall be conducted on tubes where glass or aramid fibre has a load-sharing application. One tube shall be tested in accordance with, and meet the requirement of, [A.12](#).

A sub-scale tube, as defined in [6.5.2.1.3](#), may be used in place of a full size tube for this test.

6.5.2.11 Extreme temperature pressure cycling test

One tube shall be tested in accordance with, and meet the requirements of, [A.2](#).

A sub-scale tube, as defined in [6.5.2.1.2](#), may be used in place of a full size tube for this test.

6.5.2.12 External loads test

Tubes covered by the requirements of this document are permanently mounted in a transport frame. Requirements regarding the external loads arising from transporting the tubes are specified in [Clause 9](#).

Tubes and their interface with the transport frame are to meet all loads arising from the requirements of [9.6](#).

6.5.2.13 Impact test

One tube shall be subjected to:

- a) a leak test in accordance with the requirements of [A.4](#);
- b) a blunt impact test in accordance with the requirements of [A.22](#) followed by a 1 000 cycle ambient pressure test in accordance with the requirements of [A.7](#).

If the tube fails before the specified number of cycles is reached, the failure mode shall be a leak and not a rupture. Rupture of the tube shall constitute failure to meet the test requirements.

A sub-scale tube, as defined in [6.5.2.1.2](#), may be used in place of a full size tube for this test.

NOTE Caution is used when carrying out these tests as tubes have been subjected to conditioning that could affect their pressure integrity.

6.5.2.14 Boss torque test

One tube shall be tested in accordance with, and meet the requirements of, [A.17](#).

A sub-scale tube, as defined in [6.5.2.1.2](#), may be used in place of a full size tube for this test.

6.5.2.15 Permeation test

This test is applicable to Type 4 tubes only.

One tube shall be tested in accordance with, and meet the requirements of, [A.13](#).

A sub-scale tube, as defined in [6.5.2.1.3](#), may be used in place of a full size tube for this test.

6.5.2.16 Gas cycling and blow down test

This test is applicable to Type 4 tubes only.

One tube shall be tested in accordance with, and meet the requirements of, [A.19](#). The length to diameter ratio of the sub-scale shall be within $\pm 30\%$ of the full scale tube.

A sub-scale tube, as defined in [6.5.2.1.2](#), may be used in place of a full size tube for this test.

6.5.2.17 High velocity impact (gunfire) test

One tube shall be tested in accordance with, and meet the requirements of, [A.23](#).

A sub-scale tube, as defined in [6.5.2.1.2](#), may be used in place of a full size tube for this test.

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. Tubes that have had a change of design, as identified in [Table 3](#), shall be tested in accordance with, and meet, the requirements of [Table 3](#).

A pressure relief system can be changed from the system used in type approval test procedures if the new systems will detect and release pressure in equal or less time than the original system, and with equal or higher flow capacity than the original system used.

A change in tube design does not require a new fire test if the composite material specification and composite wall thickness are maintained or increased compared to the structure used in the original type approval test programme.

For a change in polymer liner material, the requirements of [6.5.2.2.1](#) shall be met.

For a change in metal liner or boss material, the requirements of [6.5.2.2.2](#) shall be met.

For a change in resin material, the requirements of [6.5.2.2.3](#) shall be met.

Table 3 — Change of design for type III and type IV tubes

Design change	Burst	Am-bient temperature cycle	Leak before break (lbb)	Bonfire	Envi-ron-mental	Flaw tolerance	High temperature creep	Accel-erated stress rupture	Ex-treme temperature cycling	Ex-ternal loads	Impact	Boss torque	Perme-ation	Gas cycling and blow down	High velocity impact
	A.6	A.7	A.1	A.9	A.8	A.10	A.11	A.12	A.2	6.5.2.12	6.5.2.13	A.17	A.13	A.19	A.23
Fibre manufacturer	X	X	—	—	—	—	—	—	—	—	—	—	—	—	—
Change in polymer liner material ^m	X	X	X	—	X	—	X	—	X	—	X	X	X	X	—
Change in liner metal alloy	X	X	X	—	X	—	X	—	—	—	X	—	—	—	—
Change in type of liner material (e.g. steel to aluminium or from metal to polymer or vice versa)	X	X	X	X	X	X	X	X	X	—	X	X	X	X	X
Change in liner thickness >10 %	X	X							X		X ⁿ		X ⁿ	X	

Table 3 (continued)

Design change	Burst	Ambient temperature cycle	Leak before break (lbb)	Bonfire	Environmental	Flaw tolerance	High temperature creep	Accelerated stress rupture	Extreme temperature pressure cycling	External loads	Impact	Boss torque	Permeation	Gas cycling and blow down	High velocity impact
	A.6	A.7	A.1	A.9	A.8	A.10	A.11	A.12	A.2	6.5.2.12	6.5.2.13	A.17	A.13	A.19	A.23
Fibre material	X	X	X	X	X	X	X	X	X	—	X	X	—	—	X
Resin material	X	X	X ^f	X	X	X	X	X	X	—	—	—	—	—	—
Diameter change ≤20 %	X	X	—	X ^a	—	—	—	—	—	—	X	—	—	—	—
Diameter change >20 % but not more than 50 %	X	X	X	X	—	X	—	—	—	—	X	—	—	—	X
Length change ≤50 %	X	—	—	X ^a	—	—	—	—	—	—	—	—	—	—	—
Length change >50 %	X	X	—	X ^a	—	—	—	—	—	—	—	—	—	—	—
Working pressure ≤20 % ^b	X	X	—	X	—	—	—	—	—	—	—	—	—	—	—
Working pressure >20 %	X	X	X	X	—	X	X	X	—	—	X	X	X	X	X
Dome shapes	X	X	X	—	—	—	—	—	—	—	—	X ^c	X	X	—
Boss/liner interface change	X	X	—	—	—	—	—	—	—	—	—	X	—	X ^d	—

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Table 3 (continued)

Design change	Burst	Ambient temperature cycle	Leak before break (lbb)	Bonfire	Environmental	Flaw tolerance	High temperature creep	Accelerated stress rupture	Extreme temperature pressure cycling	External loads	Impact	Boss torque	Permeation	Gas cycling and blow down	High velocity impact
	A.6	A.7	A.1	A.9	A.8	A.10	A.11	A.12	A.2	6.5.2.12	6.5.2.13	A.17	A.13	A.19	A.23
Boss material change	X	X	—	—	—	—	—	—	—	—	—	X	—	—	—
Opening size and thread size	X	X	—	—	—	—	—	—	—	—	—	X	—	—	—
Coating change ^k	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—
End boss design	—	—	—	—	—	—	—	—	—	X ^e	—	X ^c	—	X	—
Change in manufacturing process	X ^h	X ^h	—	—	—	—	—	—	—	—	—	—	—	—	—
Pressure relief system	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—

Table 3 (continued)

Design change	Burst	Ambient temperature cycle	Leak before break (lbb)	Bonfire	Environmental	Flaw tolerance	High temperature creep	Accelerated stress rupture	Extreme temperature pressure cycling	External loads	Impact	Boss torque	Permeation	Gas cycling and blow down	High velocity impact	
	A.6	A.7	A.1	A.9	A.8	A.10	A.11	A.12	A.2	6.5.2.12	6.5.2.13	A.17	A.13	A.19	A.23	
Valve, fitting, or piping	—	—	—	—	—	—	—	—	—	—	—	—	—	X ^l	—	
<p>a Test only required when the length, diameter, or working pressure increases.</p> <p>b Only when thickness change proportional to diameter and/or pressure change.</p> <p>c Only when the interface between the end boss and liner, or between the end boss and composite change.</p> <p>d The gas cycle/blowdown test shall be carried out when there is a change to the design drawing of the boss/liner interface. The test may be conducted on a representative sub-scale tube.</p> <p>e Only when a change will increase stress in or deflection of the boss due to external loading specified in 6.5.2.12.</p> <p>f Only when the new resin formulation has a reduced elongation to failure.</p> <p>g Only when the outer dome liner contour deviates outside of the drawing constraints of the qualified design or when the liner material becomes thinner than the minimum wall thickness anywhere in the original design.</p> <p>h Not required for a change in autofrettage if pressure is changed less than ±5 %.</p> <p>i (Not used).</p> <p>j Required if changing between glass, aramid, and carbon.</p> <p>k Not required if changing to chemically equivalent materials (same basic chemical structure {chemical functional group}, and within the tolerances set by the manufacturer's specification).</p> <p>l For any change of design that increases the blowdown rate.</p> <p>m For a change in chemical structure or backbone of the monomer (change in molecular chain length of the polymer within manufacturer's specification does not require retest).</p> <p>n For a decrease in thickness.</p>																

6.6 Batch tests

6.6.1 General requirements

Batch testing shall be conducted on each group of not more than 200 finished tubes having the same nominal diameter, wall thickness, design, material of construction, manufacturing process and specified properties (plus any tubes and liners required for destructive testing) representative of normal production, complete with identification marks. The batch burst test and cycle test may be conducted at the start of production of the batch, or during the batch.

If less than 200 tubes are produced in one year, at least one batch test has to be performed.

All test results shall be recorded.

NOTE The manufacturer is to ensure that the properties obtained during batch testing, especially for the burst test results, are representative when compared with those obtained during the prototype testing programme, for each design.

6.6.2 Required inspection and tests

6.6.2.1 Burst test

One tube shall be subjected to a hydraulic burst test in accordance with, and meet the requirements of, [A.6](#).

If the burst pressure is less than the minimum design burst pressure, the procedure specified in [6.9](#) shall be followed.

6.6.2.2 Ambient pressure cycle test

This test is not mandatory if the tube has met the requirements of [A.1](#) without leakage or rupture during prototype testing.

One tube shall be subjected to a cyclic fatigue test at ambient temperature in accordance with, and meet the requirements of, [A.7](#). The tube shall not leak or rupture before being cycled for a total of the specified service life in years multiplied by 750 cycles.

6.6.2.3 General tests

For one tube, liner or witness sample representative of a finished tube as noted below:

- a) check component and assembly dimensions against drawing requirements (see [5.2.3.2](#));
- b) conduct one tensile test on the polymer liner or witness sample in accordance with, and meet, the requirements of [A.14](#), or provide a material certificate of conformance from the polymer supplier. The test results shall meet the requirements of the design (see [5.2.3.2](#));
- c) conduct a test to determine the melt temperature of the polymer liner or witness sample in accordance with the requirements of [A.15](#), or, obtain a material certificate of conformance from the polymer supplier. The test results shall meet the requirements of the design (see [5.2.3.2](#));
- d) conduct one tensile test on a metal liner or witness sample, or boss, in accordance with the requirements of [6.2.1.1](#), or, obtain a material certificate of conformance from the material supplier. The test results shall satisfy the requirements of the design (see [5.2.3.2](#));
- e) for steel liners, conduct three impact tests or witness sample in accordance with the requirements of [6.2.1.1](#). The test results shall meet the requirements of [6.2.1.1](#) and the design documentation;
- f) and when a protective coating is a part of the design, conduct a coating batch test on a tube in accordance with, and meet, the requirements of [A.16](#). Where the coating fails to meet the

requirements of [A.16](#), the batch shall be 100 % inspected so as to identify and remove similarly defectively coated tubes. The coating on all defectively coated tubes may be stripped using a method that does not affect the integrity of the composite wrapping and then recoated. The coating batch test shall then be repeated.

All tubes or liners from a batch where a tube or liner has failed the batch test shall follow the procedures specified in [6.9](#).

6.7 Production tests and examinations

Production examinations and tests shall be carried out on all tubes and metal liners. Tests and examinations performed to demonstrate compliance with this document shall be conducted using instruments calibrated before being put into service and thereafter according to an established program.

Each tube and/or liner shall be examined or tested:

- a) to verify that the dimensions and mass of the completed tube are within design tolerances;
- b) for metallic liners, to verify conformance to the specified surface finish with special attention being paid to deep-drawn surfaces and folds or laps in the neck or shoulder of forged or spun end closures or openings;
- c) to verify the markings;
- d) by performing a hydraulic test to the test pressure of the finished tube in accordance with the requirements of [A.5](#), Test A or Test B;
- e) for Type 4 tubes only, by performing a leak test in accordance with, and meet the requirements of, [A.4](#) (it is recommended that the tube assembly be inspected for leaks at time of first fill with the intended contents);
- f) heat treated metallic liners and end bosses shall meet the requirements of the manufacturers specification [the hardness specification shall be as defined in material property data (see [5.2.3.5](#))] — this requirement is not applicable if the metallic material used is specified with a hardness requirement and a hardness measurement is included in the material certificate;
- g) the tube and frame assembly, including all components (e.g. valves and pipework) exposed to working pressure in normal service, shall be checked for leakage at the time of first fill to at least nominal working pressure.

6.8 Batch acceptance certificate

If the results of the tests carried out in accordance with the requirements of [6.6](#) and [6.7](#) are satisfactory, the manufacturer shall issue an acceptance certificate. An example of a report form that may be used is given in [Annex B](#).

6.9 Failure to meet test requirements

In the event that the tube or component fails to meet the test requirements, the cause of the failure shall be determined.

If there is evidence of a fault in carrying out a particular test, or an error of measurement, the results of the test are not valid. If the first test did not cause damage to the tube or component, such that the test results would be compromised, it shall be retested. If the first test did cause damage to the tube or component, a new tube or component shall be selected and tested.

If there is evidence that the original heat treatment is inadequate, one reheat treatment of metal liners or bosses is allowed. Reheat treated metal liners or bosses shall meet strength test requirements of [6.2.1.1](#) for all metals, the impact requirements of [6.2.1.1](#) for steel, and the dimensional requirements

of drawings (see 5.2.3.2) for liners and bosses. Reheat treated metal liners or bosses that pass all required tests shall be considered as a new batch, and may be placed in service. If they do not meet these requirements, they shall be rejected. Further heat treatment shall not be permitted.

If there is no evidence of a fault in carrying out a particular test, or an error of measurement, and no evidence that the original heat treatment of metal liners or bosses is inadequate, then the cause of the failure shall be attributed to a defective tube or component. If the cause of the failure is identified, all tubes or components with similar defect shall be rejected. If the cause of the failure is not identified, all tubes or components in the batch shall be rejected.

Tubes or components of batches from which defective tubes or components have been removed shall be considered as a new batch. They shall be subject to all tests required of a batch. If the requirements of the batch are not met, all tubes or components in the new batch shall be rejected. If the new batch passes the required tests, the tubes or components may be placed in service.

Rejected tubes or components that can be repaired may be repaired. The repair process shall use a written repair specification. Repaired tubes or components shall pass all required tests. Repaired tubes or components that pass all required tests shall be considered as a new batch, and may be placed in service. If a repaired tube or component fails a test, all tubes or components in the represented batch shall be rejected and rendered unserviceable.

Rejected tubes or components that cannot be reheat treated or repaired shall not be placed in service and shall be rendered unserviceable.

7 Marking

7.1 General

Tubes shall be permanently and legibly marked in accordance with ISO 13769. If an adhesive label is used, a separate permanent marking on the tube shall be applied so that it can be identified if the adhesive label is unreadable.

If the adhesive label is damaged or lost and the tube can be uniquely identified, the manufacturer shall be contacted and a new adhesive label can be provided. The new label shall be of the same material and be attached to the tube in the same way as the original.

7.2 Additional marking

7.2.1 General

The following information, where applicable, shall be permanently and legibly marked on the tube with a permanent, durable label on the surface or by a label embedded in the resin or under a glass fibre layer:

- a) where a tube is used for dedicated gas service:

WARNING — THIS TUBE SHALL BE FILLED ONLY WITH <<Named Gas(es)>>;

- b) on all tubes:

WARNING — THIS TUBE SHALL BE USED ONLY WITH A <<Manufacturer Specified>> FIRE PROTECTION SYSTEM; and

- c) If fitting torque does not correspond to the values given in ISO 13341:

MAXIMUM FITTING TORQUE <<(manufacturer's recommended torque)>> and

- d) NOTICE — THIS TUBE IS TESTED FOR EXTERNAL IMPACT ENERGY <<manufacturer to specify either 488 J or 1 200 J>>.

7.2.2 Positioning of additional markings

Additional markings (e.g. re-test dates, customer names) can be included in the main label or applied as a secondary label securely affixed to the tube.

7.2.3 Letter size

All labels shall include letters not less than 6 mm high.

8 Preparation for dispatch

Prior to dispatch, every tube shall be internally clean and dry. Tubes not immediately closed by the fitting of a valve or safety device (if applicable), shall have plugs, which prevent entry of moisture and protect threads, fitted to all openings.

The manufacturer's statement of service and all necessary information and instructions to ensure the proper handling, use and in-service inspection of the tube shall be supplied to the purchaser. The statement of service shall be in accordance with the requirements of [5.2.3.1](#).

Guidance on the content of the instructions is given in [Annex D](#).

9 Requirements for frames, mounting and fitting

9.1 General

All tubes shall be permanently mounted in an appropriate frame or assembly that has sufficient strength and durability for its intended use, as demonstrated by meeting the requirements of [9.5](#) and [9.6](#). Permanent mounting of a tube may include, but is not limited to, the use of a strap mounting arrangement or the use of mounting features on the end bosses.

Tubes shall not come in direct contact with each other when in service. The expansion of the tubes in the axial and transverse directions due to pressure or temperature change shall be addressed in the design of the mounting frame, with consideration for both growth and loading.

Tube(s) mounted in the frame shall be identified (e.g. tube identification and position) by installing a marking plate permanently mounted to the frame.

The manufacturer of an assembly in accordance with this document is responsible for providing a final complete assembly, including the tubes, fittings, valves and manifold that has been tested for gas leak-tightness. Leak tightness shall be verified before placing the assembly in service.

Frames used in intermodal service shall meet the requirements of [9.3](#). Frames not used in intermodal service shall meet the requirements of [9.4](#).

9.2 Frame materials

The structural frame material shall be steel, steel alloy, stainless steel, or aluminium alloy. Protective coatings may be applied. Protective coatings are recommended to reduce corrosion of the frame, and should take into consideration the local operating environment. Potential for corrosion between the frame and the boss for boss-mounted tubes should be considered. Non-structural panels and coverings may be of any material.

9.3 Interchangeable frames for intermodal service

Frames with tubes for intermodal service (ship, rail, truck) shall meet:

- a) the requirements of the International Convention for Safe Containers (CSC),

- b) the requirements of ISO 1496-3, including the frame tests identified in 9.5, and
- c) the load requirements of 9.6.

9.4 Mounting frames for compressed gas service (non-intermodal)

Mounting frames with tubes permanently mounted for dedicated compressed gas transport service shall meet:

- a) The frame test requirements of ISO 1496-3 identified in 9.5 (but are not subject to requirements for length, width, height, and ISO/CSC markings), and
- b) The load requirements of 9.6.

Each mounting frame shall be designed to lessen the potential for loss of contents due to an accident including rollover. At a minimum, the design shall address all valves and piping components in direct communication with the contents (up to and including the first closed shutoff valve) that shall be installed:

- within the envelope of the tube or end plug;
- within the frame; or
- within a collision-resistant guard, protective device, or housing.

9.5 Mounting frame testing

The frame shall be tested in accordance with ISO 1496-3:1995, with the loading requirements reflecting the weight of the tubes, plumbing, and contained gases, per the following clauses:

- a) ISO 1496-3:1995, 6.3 — Test No. 2, Top Lift, if lift points are provided;
- b) ISO 1496-3:1995, 6.4 — Test No. 3, Bottom Lift, if lift points are provided;
- c) ISO 1496-3:1995, 6.5 — Test No. 4, External Restraint (Longitudinal);
- d) ISO 1496-3:1995, 6.6 — Test No. 5, Internal Restraint (Longitudinal);
- e) ISO 1496-3:1995, 6.7 — Test No. 6, Internal Restraint (Lateral);
- f) ISO 1496-3:1995, 6.8 — Test No. 7, Rigidity (Transverse);
- g) ISO 1496-3:1995, 6.9 — Test No. 8, Rigidity (Longitudinal);
- h) ISO 1496-3:1995, 6.11 — Test No. 10, Walkways (if applicable).

9.6 Mounting frames static loads

The tube and mounting assembly shall be able to withstand these static loads, applied separately, for a minimum of 10 min in each direction, without release of the tubes from the frame or failure of a valve or manifold line that would allow release of compressed gas:

- a) a force equal to two (2) times the weight of the tube(s) plus the maximum weight of the contents in the forward direction of travel;
- b) a force equal to one (1) times the weight of the tube(s) plus the maximum weight of the contents in the reverse direction of travel;
- c) a force equal to two (2) times the weight of the tube(s) plus the maximum weight of the contents horizontally at 90 degrees to the direction of travel;

- d) a force equal to two (2) times the weight of the tube(s) plus the maximum weight of the contents vertically downwards;
- e) a force equal to one (1) times the weight of the tube(s) plus the maximum weight of the contents vertically upwards.

These static loads shall be applied at the tube/frame interface points as appropriate, using suitable loading methods such as:

- a) application of load using tooling or equipment, or
- b) application of load using actual tubes with contents to achieve the required loads, or
- c) application of load using a steel bar or tube, with added weights as required, to achieve the required loads, and

these loads shall be reacted through the points where the frame would interface with its mounting points to the chassis.

9.7 Piping, valves, fittings and manifold components

Piping, valves, fittings, and any manifolds shall be designed with a test pressure at least 1,5 times the working pressure of the tube. The burst pressure shall be at least 1,5 times the test pressure.

Piping, valves, fittings, and any manifolds that are pressurized during transportation shall, to the extent possible, be protected from damage that might occur during an accident. The protection may be provided, for example, by enclosing the components in a cabinet or by the use of shielding panels. Excess flow devices that limit the escape of compressed gas in the event of an accident may also be incorporated.

Piping, valves, fittings, and manifolds shall not extend beyond the envelope of the transportation frame.

Piping shall be supported at sufficient intervals to limit loading due to shock and vibration. Piping shall have expansion loops or equivalent to limit loads due to loads caused by relative motion between the composite tubes.

The piping system and fire protection system shall be designed so as to prevent the accumulation of water in the piping or other components that results in malfunction of the fire protection system.

It is recommended that the plumbing assembly be inspected for leaks at time of first fill with the intended contents.

9.8 Change of design

A change of design is any change in the selection of structural materials, dimensional change not attributable to normal manufacturing tolerances, or change in the loading from the combined weight of the tubes and contained gases.

Frames that have had a change of design shall be tested in accordance with, and meet, the requirements of [Table 4](#).

Table 4 — Change of design

Design change	Stress analysis	Top lift	Bottom lift	External restraint (long.)	Internal restraint (long.)	Internal restraint (lat.)	Rigidity (trans)	Rigidity (long)	Walkways	Static loads
Material strength increase	X	—	—	—	—	—	—	—	—	—
Material strength decrease	X	X	X	X	X	X	—	—	X	X
Material thickness increase	X	—	—	—	—	—	—	—	—	—
Material thickness decrease	X	—	X	X	X	X	X	X	X	X
Change in frame length >5 %	X	X	X	—	—	X	—	—	—	X
Change in frame width >5 %	X	—	—	—	—	—	—	—	—	X
Change in frame height >10 %	X	—	—	—	—	—	—	—	—	X
Decrease in loading	X	—	—	—	—	—	—	—	—	—
Increase in loading >10 %	X	X	X	X	X	X	—	—	—	X

Annex A (normative)

Test methods and criteria

A.1 Leak-before-break (LBB) test

Finished tubes shall be pressure cycled by:

- a) filling the tube to be tested with a non-corrosive fluid (e.g. oil, inhibited water or glycol);
- b) cycling the pressure in the tube between:
 - 1) a lower pressure not to exceed 10 % of the working pressure or a maximum 30 bar;
 - 2) an upper pressure not less than 150 % of working pressure;
- c) The cycling rate shall not exceed 10 cycles per minute.

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

Tubes shall not leak or rupture for the first 10 cycles. Tubes may leak, but shall not rupture, between 10 cycles and three times the number of filling cycles (750 cycles multiplied by specified number of intended years in service). Tubes that do not leak or rupture after three times the number of filling cycles have fully met the requirements of this test.

A.2 Extreme temperature pressure cycling test

Unless the tube should have an integral coating necessary for it to meet its design and test requirements, finished tubes, with the composite wrapping free of any protective coating, shall be cycle tested by:

- a) conditioning the tube for 48 h at zero to 10 % of the working pressure, between a temperature 65 °C and 70 °C and 95 % or greater relative humidity (the intent of this requirement shall be deemed met by spraying the tube with a fine spray or mist of water in a chamber held at 65 °C or higher);
- b) for multipurpose gas service, maintaining a tube surface temperature of between 65 °C and 70 °C and cycling the pressure in the tube for 5 000 cycles, between 10 % of working pressure or a maximum of 30 bar and 150 % of the working pressure;
- c) for dedicated gas service, maintaining a tube surface temperature of between 65 °C and 70 °C and cycling the pressure in the tube for 5 000 cycles at maximum developed pressure at 65 °C;
- d) releasing the pressure and stabilizing the tube at a temperature of approximately 20 °C;
- e) stabilize the tube and the contained pressurizing medium until the tube surface temperature is between –40 °C and –50 °C. The hydraulic pressurizing medium external to the tube under test may remain at ambient temperature. Once the tube has reached its equilibrium temperature, it shall be pressure cycled by applying 5 000 cycles from a pressure less than 10 % of working pressure or maximum 30 bar to 100 % of working pressure.

The tube surface temperature shall be maintained at between –40 °C and –50 °C by regulating the environmental chamber and the pressure cycling frequency. The pressurizing fluid shall be selected to ensure that it functions at the temperatures specified in the various tests.

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

Following the completion of the test, the tube shall be hydrostatically pressured to failure in accordance with the requirements of A.6 and achieve a minimum burst pressure of 85 % of the minimum design burst pressure.

A.3 Coating tests

Coatings shall be evaluated by:

- a) adhesion testing, in accordance with the requirements of 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 the requirements of ASTM D522, test method B with a 12,7 mm mandrel at the specified thickness at -20 °C. Samples for the flexibility test shall be prepared in accordance with the requirements of ASTM D522. The coating shall exhibit no visually apparent cracks;
- c) impact resistance, in accordance with the requirements of ASTM D2794. The coating at ambient temperature, but not less than -15 °C or higher than 40 °C, shall pass the forward impact test at an energy of 18 J;
- d) chemical resistance, in accordance with the requirements of ASTM D1308 except that:
 - 1) the tests shall be conducted using the open spot test method and 100 h exposure to a 30 % sulfuric acid solution (acid with a specific gravity of 1,219); and
 - 2) 24 h exposure to a polyalkalene glycol (e.g. brake fluid);
 - 3) there shall be no evidence of lifting, blistering or softening of the coating;
 - 4) the coating adhesion shall achieve a rating of 3 when tested in accordance with the requirements of ISO 4624;
- e) being exposed for a minimum of 1 000 h in accordance with the requirements of ASTM G154 using a UVA 340 lamp. The coating shall exhibit no evidence of blistering. The coating adhesion to the tube shall achieve a rating of 3 when tested in accordance with the requirements of ISO 4624. The maximum gloss loss allowed is 20 %;
- f) being exposed to a salt spray for a minimum of 1 000 h for a steel liner coating, and for a minimum 500 h for other coatings, in accordance with the requirements of ISO 9227. Undercutting shall not exceed 2 mm at the scribe mark, there shall be no evidence of blistering of the coating and adhesion shall achieve a rating of 3 when tested in accordance with the requirements of ISO 4624;
- g) being exposed to a resistance to chipping test at room temperature in accordance with the requirements of ASTM D3170. The coating shall achieve a rating of 7A or better and there shall be no exposure of the substrate.

A.4 Leak test

Finished tubes shall be leak tested by (an alternative acceptable method may be used such as bubble testing using dry air or gas, or measurement of trace gases using a mass spectrometer, portable gas detector, or other suitable technique):

- a) pressurizing the tubes with water or other suitable fluid to working pressure; and
- b) with the tube having been pressurized for at least 15 min, carefully examining it for signs of leakage (e.g. a visual indication or decrease in pressure).

Any leakage detected shall be cause for rejection.

A.5 Hydraulic pressure test

A.5.1 General

Adequate safety precautions shall be taken while this test is being carried out.

If leakage occurs in the piping or fittings, the tubes shall be re-tested after repairing the leaks.

The test pressure tolerance shall be +3 % or +10 bar, whichever is the lower.

Pressure gauges with the appropriate level of accuracy shall be used.

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

Alternatively, a pneumatic pressure test can be carried out provided that appropriate measures are taken to ensure it is carried out safely and any energy released can be safely contained (which is considerably more than in the hydraulic test).

Either test A or test B shall be carried out.

A.5.2 Test A — Volumetric expansion test

The tube shall be hydrostatically tested to 150 % of its working pressure. Increase the pressure in the tube gradually and regularly until 150 % of working pressure is reached.

The test pressure shall be maintained in the tube for a minimum of 2 min or sufficiently longer so as to ensure complete expansion.

If the test pressure cannot be maintained due to failure of the test apparatus, it is permissible to repeat the test.

Any tube not meeting the defined rejection limit defined by manufacturer in the design data shall be rejected and rendered unserviceable.

A.5.3 Test B — Proof pressure test

When carrying out the pressure test, a suitable fluid (normally water) shall be used as the test medium.

Increase the pressure in the tube gradually and regularly until 150 % of working pressure is reached.

The test pressure shall be maintained in the tube for at least 2 min with the tube isolated from the pressure source, during which time there shall be no decrease in the recorded pressure or evidence of any leakage.

If the test pressure cannot be maintained due to failure of the test apparatus, it is permissible to repeat the test.

Any tube which exhibits a decrease in recorded pressure or evidence of leakage shall be rejected and rendered unserviceable.

A.6 Burst test

The rate of pressurization shall not exceed 10 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 tube shall be placed 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 no less than the value necessary to meet the stress ratio requirements. Actual burst pressure shall be recorded.

Rupture may occur in either the cylindrical part of the tube or the dome. The test may be terminated upon exceeding the minimum required burst pressure and required hold time without actually bursting the tube.

A tube that has passed the minimum burst requirements without rupture, shall be rendered unserviceable.

A.7 Ambient temperature cycle test

Pressure cycling shall be performed by:

- a) filling the tube to be tested with a non-corrosive fluid (e.g. oil, inhibited water or glycol);
- b) cycling the pressure in the tube between 10 % of the working pressure or maximum of 30 bar and:
 - 1) 150 % of the working pressure for multipurpose gas service at a rate not exceeding 10 cycles per minute. Maximum pressurization rate shall be 27,5 bar/sec; or
 - 2) maximum developed pressure at 65 °C for dedicated gas service at a rate not exceeding 10 cycles per minute. Maximum pressurization rate shall be 27,5 bar/sec.

The tubes shall not fail by leakage or rupture before reaching the number of filling cycles defined as the specified service life in years multiplied by 750.

Tubes passing the test may be used in other qualification or batch tests, but shall not be placed in service.

Any tubes not meeting the requirements in [6.5.2.4](#) shall be rejected and rendered unserviceable.

A.8 Environmental test

A.8.1 General

Environmental testing shall be carried out on one finished tube in accordance with the requirements, sequentially, of [A.8.2](#) to [A.8.5](#).

The upper section of the tube is to be divided into five distinct areas and marked for pendulum impact preconditioning and fluid exposure. The five areas shall be nominally 100 mm in diameter.

While it might be convenient for testing, the five areas need not be oriented along a single line but they shall not overlap.

A.8.2 Pendulum impact preconditioning

The tube shall be unpressurized during preconditioning.

The pendulum impact body shall be of steel and have the shape of an equilateral pyramid with a square base, the summit and the edges being rounded to a radius of 3 mm. The centre of percussion of the pendulum shall coincide with the centre of gravity of the pyramid and its distance from the axis of rotation of the pendulum shall be 1 m.

The total mass of the pendulum referred to its centre of percussion shall be 15 kg. The energy of the pendulum at the moment of impact shall be not less than 30 Nm and as close to that value as possible.

The tube shall be held in position by its end bosses or by the intended mounting brackets.

Each of the five areas shall be preconditioned by impact of the pendulum body summit at the centre of the area.

A.8.3 Environmental fluids exposure

Each marked area on the tube shall be exposed to one of these solutions:

- a) Sulfuric acid: 19 % solution by volume in water;
- b) Sodium hydroxide: 25 % solution by weight in water;
- c) Methanol/gasoline: 5/95 % concentration of M5 fuel meeting the requirements of ASTM D4814;
- d) Ammonium nitrate: 28 % by weight in water; and
- e) Windshield washer fluid (50 % by volume solution of methyl alcohol and water).

The tube shall be oriented with the exposure areas uppermost. A pad of glass wool approximately 0,5 mm thick and between 90 and 100 mm in diameter is to be placed on the area to be tested. Apply an amount of the test fluid to be used to the glass wool sufficient to ensure that the pad is wetted evenly across its surface and through its thickness for the duration of the pressure cycle and pressure hold test.

NOTE It is intended that the concentration of the fluid is not changed significantly during the duration of the test.

A.8.4 Pressure cycle and pressure hold test

The tube shall be hydraulically pressure cycled between a lower pressure of less than or equal to 10 % of its working pressure or a maximum 30 bar and an upper pressure of:

- a) for multipurpose gas service tubes, 150 % times working pressure; or
- b) for dedicated gas service tubes, a maximum developed pressure at 65 °C,

for a total of 3 000 cycles. The maximum pressurization rate shall be 27,5 bar per second. The tube shall not leak.

After pressure cycling, the tube shall be pressurized to 150 % of working pressure and held at that pressure for a minimum of 24 h and until the elapsed exposure time (pressure cycling and pressure hold) to the environmental fluids equals 48 h.

A.8.5 Acceptable results

To pass the tests described in [A.8.2](#) to [A.8.4](#), the residual burst pressure of the tube shall be no less than 1,8 times the working pressure when tested in accordance with the requirements of [A.6](#).

A.9 Bonfire test

A.9.1 General

The bonfire test is designed to demonstrate that finished tubes, mounted in frame, complete with the fire protection system (e.g. tube valve, pressure relief system, fire detection system and/or integral thermal insulation, if included in the design) specified in the design, will prevent rupture of the tube when tested under the specified fire conditions.

For tubes not equipped with individual temperature-activated pressure relief devices (TPRD), a tube without TPRD shall be exposed for fire until rupture (burst or leak) (minimum 20 min). Time to burst shall be used for design of the pressure relief system of the integrated structure.

Precautions for a pressure wave and fragments from the tube and test facility shall be taken during fire testing in the event that tube rupture occurs.

A.9.2 Frame set-up

This test shall be performed with minimum of one tube mounted as intended in a frame, either horizontally or vertically.

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

If only one tube is mounted in the frame, but the pressure relieve system is intended to release gas from multiple tubes through a common fire release system, additional tubes, remotely placed away from the fire, shall be connected to the release system, demonstrating the release capacity of the pressure relieve system for the total volume of the tubes to be vented.

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, the fault rectified, and the test repeated.

A.9.3 Fire source

In the case of horizontal mounted tubes, one fire source shall be used, 1,65 m × 1,65 m, placed at a point that is longitudinally half-way between the two PRDs with the greatest distance between them, and placed under the longitudinal axis of tube(s).

In the case of vertically mounted tubes, one fire source shall be used, and placed under the frame so that the centre of the fire source shall be under the centre line of the tube. If PRDs are not provided on each tube, the fire shall be placed under a tube that is located furthest from the tube containing the PRD.

In the case of a horizontally mounted tube having a fire safety system without a PRD, two fire sources shall be used, one placed in the centre of the tube and one placed under the dome of one end. Any fuel may be used for the fire source provided it supplies uniform heat sufficient to maintain the specified test temperatures until the tube 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 heat input to the tube under test is reproducible.

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

A.9.4 Temperature and pressure measurement

Tube surface temperatures shall be monitored by at least three thermocouples located along the bottom of the horizontally mounted tube closest to the fire source and spaced not more than 0,75 m apart. For vertically mounted tubes, at least one thermocouple shall be located at the tube end closest to the fire. If more than one thermocouple is used at each location, an average temperature at each location can be used.

Thermocouple temperatures and the tube pressure shall be recorded every 30 s or less during the test.

A.9.5 General test requirements

The tube(s) shall be pressurized to working pressure with compressed nitrogen, or with the intended contents for dedicated service, and tested at working pressure.

The fire shall produce flame that impinges on the surface of the frame along a 1,65 m length of the tube if horizontally mounted, or the tube end near the fire if vertically mounted, within one minute following ignition.

Within 5 min of the fire being ignited, the temperature measured by at least one thermocouple on the bottom of the tube shall be ≥ 590 °C. This minimum temperature shall be maintained for the remainder of the test.

A.9.6 Acceptable results

The tube shall vent through the specified pressure relief system (PRD if applicable) or pass the bonfire test without rupturing.

If the test is to be carried out on a tube in a frame without a PRD installed, the tube shall resist the fire without leakage or rupture for the manufacturers recommended time but not less than 20 min followed by a 20 min hold with the fire extinguished and thereafter be depressurized simulating the safe release of gas after a fire event.

A.10 Composite flaw tolerance tests

One finished tube, complete with protective coating if integral to the design, shall have flaws cut into the composite of the tube sidewall in the longitudinal direction.

The flaws shall be greater than the visual inspection limits as specified by the manufacturer. As a minimum, the flaw length and depth shall be:

- a) for tubes up to 0,6 m diameter, one flaw shall be 25 mm long and 1,25 mm in depth and a second flaw shall be 200 mm long and 0,75 mm in depth; and
- b) for tubes of 0,6 m diameter and larger, one flaw shall be 130 mm long and 2,5 mm in depth and a second flaw shall be 1 000 mm long and 1,5 mm in depth.

The flawed tube shall then be pressure cycled between 10 % and 150 % of working pressure at ambient temperature, initially for 3 000 cycles, then followed by additional cycles representing its specified lifetime. For dedicated gas service, the flawed tube may instead be cycled between 10 % and maximum developed pressure at 65 °C for the same number of cycles.

The tube shall not leak or rupture within the first 3 000 cycles, but may fail by leakage during the further testing up to its specified lifetime.

All tubes which are subjected to this test shall be rendered unserviceable.

A.11 High temperature creep test

One finished tube shall be heated up and hydraulically pressurized to 1,5 times working pressure at a temperature of 100 °C and held at that temperature for not less than 200 h.

The tube shall meet the requirements of:

- a) the hydraulic expansion test described in [A.5.2](#); and
- b) the leak test described in [A.4](#); and
- c) the hydraulic pressure burst test described in [A.6](#).

NOTE The pressure shall be actively managed during heating to avoid overpressurization.

A.12 Accelerated stress rupture test — Glass or aramid fibre tubes only

One tube shall be preconditioned to working pressure and to a temperature of 65 °C and held at this pressure and temperature for 1 000 h.

The tube shall then be pressured to burst in accordance with the procedure described in [A.6](#), except that the burst pressure shall exceed 85 % of the minimum design burst pressure.

A.13 Permeation test

One finished tube shall be filled with the intended contents or suitable trace gas to working pressure, placed in an enclosed sealed chamber at ambient temperature and monitored for permeation for 500 h.

The measured permeation rate shall not be more than equivalent to 6 Ncm³/h/l hydrogen or to 0,25 Ncm³/h/l for compressed natural gas.

NOTE 1 The hydrogen permeation rate and unit is used in Regulation (EC) No 79/2009 for the type-approval of hydrogen-powered motor vehicles. The compressed natural gas permeation rate is from ISO 11439.

The measured permeation rate shall be recorded.

If a trace gas is used, correlation between the trace gas and hydrogen or compressed natural gas shall be provided.

NOTE 2 Correlation can be provided by analysis comparing permeability of gases, or actual measurement on a subscale vessel.

A.14 Tensile properties of polymers

The tensile yield strength and ultimate elongation of polymer liner material shall be determined at -50 °C or lower in accordance with the requirements of ISO 527-2.

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

A.15 Softening temperature of polymers

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

The softening temperature shall be at least 100 °C.

A.16 Coating batch tests

A.16.1 Coating thickness

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

A.16.2 Coating adhesion

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

A.17 Boss torque test

The body of the tube 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 tube. 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 tube shall then be subjected to and pass a leak test in accordance with the requirements of [A.4](#).

A.18 Resin shear strength

Resin materials shall be tested on a sample coupon representative of the composite overwrap in accordance with the requirements of ISO 14130, or an equivalent standard.

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

A.19 Gas cycling and blow down test — Type 4 tubes only

Prior to conducting this test, tubes of this design shall have successfully passed the tests described in [A.4](#) (leak test), [A.6](#) (hydrostatic pressure burst test), [A.7](#) (ambient temperature cycle test) and [A.13](#) (permeation test).

One finished tube shall be cycle tested by:

- a) filling the tube with either the intended gas contents or nitrogen;
- b) cycling the pressure in the tube for 10 cycles, between 10 % of working pressure or maximum 30 bar and working pressure, with either the intended contents or nitrogen.

The pressure cycling rate shall provide at least a 2 h hold at the high pressure portion of the cycle;

- c) following the high pressure hold in the final cycle for 2 h, the gas shall be released freely to atmosphere.

The blow down rate (or equivalent orifice opening used) during the test shall be recorded in the test report. Any system design change resulting in a faster blow down rate (e.g. due to a larger orifice) shall require a new test.

The tube shall then be subjected to a leak test in accordance with and meet the requirements of [A.4](#).

Following the completion of the test the tube shall be sectioned and the liner and liner/end boss interface inspected.

This test is deemed to be passed if there is no evidence of liner cracking or electrostatic discharge. Alternatively, if a tube completes 1 000 filling cycles in accordance with the test procedure described above, without leaking, and without appearance of growth of liner cracking or greater evidence of electrostatic discharge, it is deemed to have passed the test.

A.20 Sulfide stress cracking test for steel

Testing shall be conducted in accordance with the requirements of NACE/TM 0177-2016, Method A.

Tests shall be conducted on a minimum of three tensile specimens with a gauge diameter of 3,81 mm machined from the wall of a finished tube 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 hydrogen sulfide (balance nitrogen).

The tested specimens shall not fail within a test duration of 144 h.

A.21 Hydrogen embrittlement test

For tubes intended for use with hydrogen and having a steel liner or steel component exposed to the gas and where the steel has a UTS value above 950 MPa, a hydrogen embrittlement test shall be carried out in accordance with, and meet, the requirements of ISO 11114-4.

A.22 Blunt impact test

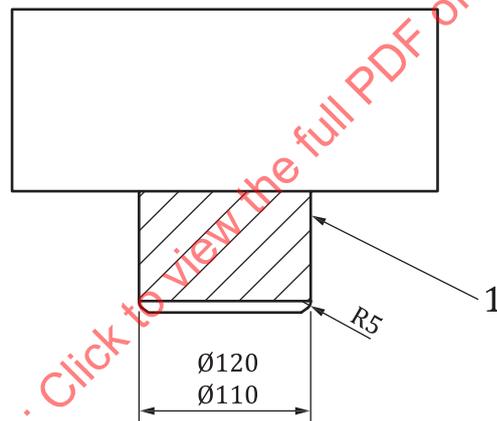
One empty tube shall be subjected to two impacts, one in each of the positions described below and shown in [Figures A.2](#) and [A.2](#):

- a) One impact shall be at the tube sidewall midway between the ends; and
- b) One impact shall be at an angle of 45° to strike the shoulder of the tube (mid arc length at the dome).

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

The tube shall be secured so as to ensure that it does not move during impact.

The impactor shall be made from steel bar and have a diameter of between 110 mm and 120 mm and strike the tube with an energy of either 488 J or 1 200 J.



Key

1 steel

Figure A.1 — Blunt impactor

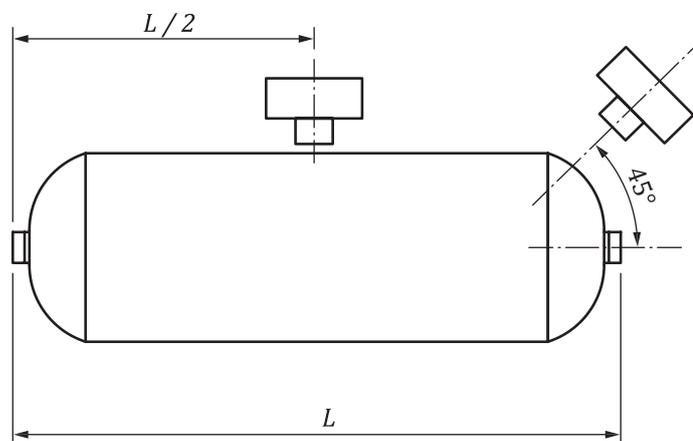


Figure A.2 — Blunt impact locations

The impacted tube shall then be pressure cycled between 10 % and 150 % of working pressure at ambient temperature, initially for 3 000 cycles, then followed by additional cycles representing its specified lifetime. For dedicated gas service, the impacted tube may instead be cycled between 10 % and maximum developed pressure at 65 °C for the same number of cycles.

The tube shall not leak or rupture within the first 3 000 cycles, but may fail by leakage during the further testing up to its specified lifetime.

A tube passing the test at an energy level of 1 200 J shall be identified as achieving Impact Resistance Level 2, which shall be reported on the statement of service in [5.2.3.1](#) and on the label per [7.2.1](#). If the tube does not pass the blunt impact test at a level of 1 200 J, a second tube shall be tested at an energy level of 488 J. A tube passing the test at an energy level of 488 J shall be identified as achieving Impact Resistance Level 1, which shall be reported on the statement of service per [5.2.3.1](#) and on the label per [7.2.1](#). A tube that does not pass at an energy level of 488 J shall not be approved.

All tubes which are subjected to this test shall be rendered unserviceable.

A.23 High velocity impact (gunfire) test

One tube shall be filled to working pressure with nitrogen or the intended contents.

The tube shall be positioned in such a way that the point of impact of the projectile shall be in the tube side wall at a nominal angle of 45° with respect to the axis of the tube and such that the bullet would also exit through the tube side wall. Tubes shall be impacted by a 7,62 mm (0,30 calibre) armour-piercing projectile (of length between 37 mm and 51 mm). The bullet shall be fired from a distance of not more than 45 m. The muzzle velocity of the bullet shall be in excess of 750 m/s.

The dimensions of the entrance and exit openings shall be measured and recorded (if applicable).

After the test, the tube shall be rendered unserviceable.

Parameters to monitor and record:

- type of projectile;
- initial pressure;
- description of failure;
- approximate size of the entrance and exit openings (if applicable).

The tube shall remain in one piece. If the tube is not penetrated by the bullet, then the tube shall have passed the test.

Annex B (informative)

Report forms

B.1 General

This annex provides guidance on the range of information to be included in the file of documentation associated with tube approval. Each report should be signed by the manufacturer.

The tube manufacturer should maintain and keep a file of the approval certificates and technical documentation.

The manufacturer's report should conform to the requirements of this annex and should be signed by the manufacturer's authorized representative.

The report should be retained for not less than 15 years or for the intended life of the tube.

Upon request, the tube manufacturer should provide the tube purchaser with not less than the information requested in the reports described in this annex.

The manufacturer's approval certificate should include, as a minimum:

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

B.2 Documentation file

B.2.1 General

The documentation file should include:

- a) Approval certificate — an example of a suitable format is given in [B.2.2](#);
- b) Certificate of conformance — to be clear and legible. An example of a suitable format is given in [B.2.3](#);
- c) Report of chemical analysis of material for metallic tubes, liners or bosses — to include essential elements, identification, etc.;
- d) Report of mechanical properties of material for metallic tubes and liners — to report all tests required by this document;

- e) Report of physical and mechanical properties of materials for non-metallic liners — to report all tests and information required in this document;
- f) Report of composite analysis — to report all tests and data required in this document;
- g) Report of hydrostatic tests, periodic pressure cycling and burst tests — to report test and data required in this document.

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