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Second edition
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Gas cylinders — Refillable composite reinforced tubes of water capacity between 450 l and 3000 l — Design, construction and testing

Bouteilles à gaz — Tubes composites renforcés rechargeables d'une capacité de 450 l à 3000 l — Conception, construction et essais

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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 ISO/TC 58, *Gas cylinders*, Subcommittee SC 3, *Cylinder design*.

This second edition cancels and replaces the first edition (ISO 11515:2013), which has been technically revised. It also incorporates the Amendment, ISO 11515:2013/Amd.1:2018. The main changes are as follows:

— the references have been updated;

— a resin shear strength test was added to the document and to Tables 2, 3 and 4,

— in 8.5.10, fire resistance test, the procedure has been changed to make the test more consistent;

— the criteria in 8.5.10.3 has been revised;

— in 8.5.15, gas cycle test, a new procedure has been added for the test to have a lower number of cycles but with a significant hold time at pressure.

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, inspection and testing of composite tubes for worldwide usage. The objective of this document is to balance design and economic efficiency against international acceptance and universal utility.

This document aims to eliminate the concern about climate, duplicate inspection and restrictions currently existing because of a lack of definitive 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[1].

Composite tubes can be used alone or in batteries to equip trailers or skids (ISO modules) or multiple element gas containers (MEGCs) for the transportation and distribution of gases. This document does not include consideration of any additional stresses that can occur during service or transport (e.g. torsional/bending stresses). However, it is important that the stresses associated with mounting the tube are considered by the assembly manufacturer and the tube manufacturer.

Gas cylinders — Refillable composite reinforced tubes of water capacity between 450 l and 3000 l — Design, construction and testing

1 Scope

This document specifies the minimum requirements for the materials, design, construction and performance testing of

— Type 2 hoop-wrapped composite tubes,

— Type 3 fully-wrapped composite tubes, and

— Type 4 fully-wrapped composite tubes

with water capacities between 450 l and 3 000 l for storage and conveyance of compressed or liquefied gases with test pressures up to and including 1 600 bar[1)] and a design life of at least 15 years.

This document is applicable to expected service temperatures between −40 °C and +65 °C.

NOTE Type 4 tubes manufactured and tested to this document are not intended to contain toxic, oxidizing or corrosive gases.

This document is applicable to tubes with composite reinforcement of carbon fibre or aramid fibre or glass fibre (or a mixture thereof) in a matrix.

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 527-1, *Plastics — Determination of tensile properties — Part 1: General principles*

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

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

ISO 4624:2016, *Paints and varnishes — Pull-off test for adhesion*

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

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

ISO 7225, *Gas cylinders — Precautionary labels*

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

ISO 9227:2017, *Corrosion tests in artificial atmospheres — Salt spray tests*

ISO 9712, *Non-destructive testing — Qualification and certification of NDT personnel*

1) 1 bar = 0,1 MPa = 10^5 Pa; 1 MPa = 1 N/mm^2.

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

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

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

ISO 10286, *Gas cylinders — Vocabulary*

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

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

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

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

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

ISO 13769, *Gas cylinders — Stamp marking*

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

ASTM 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 D2344, *Standard Test Method for Short-Beam Strength of Polymer Matrix Composite Materials and Their Laminates*

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 D7269, *Standard Test Methods for Tensile Testing of Aramid Yarns*

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

ASTM G154, *Standard Practice for Operating Fluorescent Ultraviolet (UV) Lamp Apparatus for Exposure of Non-metallic Materials*

3 Terms and definitions

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

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

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
aramid fibre
continuous filaments of aramid laid up in tow form, used for reinforcement

3.2
autofrettage
pressure application procedure which strains the metal *liner* (3.18) past its yield point sufficient to cause permanent plastic deformation, and results in the liner having compressive stresses and the fibres having tensile stresses when at zero internal gauge pressure

3.3
batch
set of homogeneous items or material

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

3.4
batch of load-sharing liners
quantity of *liners* (3.18) of the same nominal diameter, length, thickness and design, made successively from the same material cast (heat) and processed in the same heat treatment equipment (i.e. a continuous furnace process or a single furnace charge) using the same heat treatment parameters

3.5
batch of non-load sharing liners
quantity of non-load sharing liners of the same nominal diameter, length, thickness and design, made successively and subjected to the same continuous manufacturing process

3.6
batch of metal bosses
quantity of metal bosses of the same nominal diameter, length, thickness and design, made successively from the same material cast (heat) and processed in the same heat treatment equipment using the same heat treatment parameters

3.7
batch of composite tubes
quantity of up to 200 finished *tubes* (3.24) successively produced (plus finished tubes required for destructive testing), of the same nominal diameter, length, thickness and design

Note 1 to entry: The *batch* (3.3) of finished tubes can contain different batches of liners, fibres and *matrix* (3.21) materials.

3.8
burst pressure
highest pressure reached in a *tube* (3.24) or *liner* (3.18) during a burst test

3.9
carbon fibre
continuous filaments of carbon laid up in tow form, used for reinforcement

3.10
composite overwrap
combination of fibres and *matrix* (3.21) used to reinforce the *tube* (3.24), including any barrier or protective layers that are a permanent part of the design

3.11
dedicated gas service
service in which a *tube* (3.24) is used only with specified gas or gases

3.12
equivalent fibre
fibre from the same material family and similar properties to a fibre used in a previously prototype tested *tube* (3.24)

3.13
equivalent liner
liner (3.18) manufactured from the same nominal raw materials, using the same process of manufacture and having the same physical structure and the same nominal physical properties (within ±5 %) of the approved liner design

3.14
equivalent matrix
resin *matrix* (3.21) from the same chemical family and similar properties to the resin matrix used in a previously prototype tested *tube* (3.24)

3.15
exterior coating
layers of material applied to the *tube* (3.24) as protection or for cosmetic purposes

Note 1 to entry: The coating can be transparent or opaque.

3.16
glass fibre
continuous filaments of glass laid up in tow form, used for reinforcement

3.17
leak
escape of gas at a rate greater than 5×10^{-3} mbar·l/s through a defect rather than permeation

3.18
liner
inner portion of the composite *tube* (3.24), whose purpose is both to contain the gas and transmit the gas pressure to the fibres

3.19
load-sharing liner
liner (3.18) that has a *burst pressure* (3.8) greater than or equal to 5 % of the nominal burst pressure of the finished composite *tube* (3.24)

3.20
non-load-sharing liner
liner (3.18) that provides no load sharing for the finished composite *tube* (3.24)

3.21
matrix
material that is used to bind and hold the fibres in place

3.22
minimum design burst pressure
minimum *burst pressure* (3.8) specified by the manufacturer

3.23
representative composite tube
shorter *tube* (3.24) with the same nominal diameter, and manufactured using the same materials and manufacturing technique, and using a representative wrapping pattern (same number of strands and same number of layers) so as to represent an equivalent stress compared to a full-scale prototype

3.24
tube
transportable pressure receptacle with a water capacity exceeding 150 l

3.25
tubing
hollow cylindrical body of metal or other material, used for conveying or containing liquids or gases

3.26
Type 2 tube
hoop-wrapped *tube* (3.24) with a *load-sharing liner* (3.19) and composite reinforcement on the cylindrical portion only

3.27
Type 3 tube
fully wrapped *tube* (3.24) with a *load-sharing liner* (3.19) and composite reinforcement on both cylindrical portion and dome ends

3.28
Type 4 tube
fully wrapped *tube* (3.24) with a *non-load-sharing liner* (3.20) and composite reinforcement on both cylindrical portion and dome ends

3.29
glass transition temperature
T_g
temperature where a polymer substrate changes from a rigid glassy material to a soft (not melted) material, usually measured in terms of the stiffness, or modulus

4 Symbols

p_b	burst pressure of the finished tube	bar
p_h	test pressure	bar
p_{max}	maximum developed pressure at 65 °C	bar
p_w	working pressure	bar
E	notch length	mm
T	notch depth	mm
S	tube nominal wall thickness	mm
W	notch width	mm
T_g	glass transition temperature	°C
N	pressurization cycles to test pressure	—
N_d	pressurization cycles to maximum developed pressure	—
y	number of years of design life	—
t	nominal composite thickness	—
L	length of tube	m
n_1	viscosity of gas 1	µ centipoise
n_2	viscosity of gas 2	µ centipoise

Q_1	flow rate of gas 1	ACM/h (actual cubic meters/hour)
Q_2	flow rate of gas 2	ACM/h

5 Inspection and testing

To ensure that the tubes conform to this document, they shall be subject to inspection and testing in accordance with Clauses 6, 7, 8 and 9.

Tests and examinations performed to demonstrate conformity to this document shall be conducted using instruments calibrated before being put into service and thereafter according to an established programme.

NOTE Other requirements can apply in relevant national or regional regulations of the country (countries) where the tubes are intended to be used.

6 Materials

6.1 Liner materials

6.1.1 Load-sharing liner materials shall conform in all relevant respects to the appropriate International Standards:

a) seamless steel liners: ISO 9809-1, ISO 9809-2, ISO 9809-3 or ISO 11120, as appropriate;

b) seamless aluminium alloy liners: ISO 7866.

Relevant sections are those covering materials, thermal treatments, neck design, construction and workmanship and mechanical tests. Design requirements are excluded since these are specified by the manufacturer for the design of the composite tube (see 7.2.2).

6.1.2 The composite tube manufacturer shall verify that each new batch of materials has the specified properties and qualities and shall maintain records so that the cast of material and the heat treatment batch where applicable, used for the manufacture of each tube can be identified. A certificate of conformance, from the liner material manufacturer is considered acceptable for the purposes of verification.

6.1.3 The liner shall be manufactured from a metal or alloy suitable for the gas to be contained in accordance with ISO 11114-1, if applicable.

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

6.1.5 Non-load-sharing liner materials shall conform in all relevant respects to the appropriate standards, as follows:

a) The liner (including metal boss) shall be manufactured from a material suitable for the gas to be contained in accordance with ISO 11114-1 and ISO 11114-2 or demonstrated and documented by suitable testing.

b) Metal bosses that are attached to a non-load sharing liner shall fulfil the type approval testing requirements of this document.

c) The tensile yield strength and ultimate elongation of plastic liner material shall be determined at −50 °C in accordance with ISO 527-2. The test results shall demonstrate the ductile properties of the plastic liner material at temperatures of −50 °C or lower by meeting the values specified by the manufacturer.

d) Polymeric materials from finished liners shall be tested in accordance with a method described in ISO 306. The softening temperature shall be at least 100 °C.

6.2 Composite overwrap

6.2.1 The overwrap filament materials shall be carbon fibre or aramid fibre or glass fibre (or any mixture thereof).

NOTE Glass fibre reinforced composite tubes can be susceptible to chemical attack and degradation after being in contact with aggressive acids (e.g. battery acid).

6.2.2 The resin matrix shall be a thermosetting or thermoplastic polymer suited to the application, environment and intended life of the product, for example, epoxy or modified epoxy with an amine or anhydride curing agent, vinyl esters and polyesters.

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

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

6.2.5 The batches of materials shall be identified, documented and supplied to the inspector.

6.2.6 The manufacturer shall ensure that there is no adverse reaction between the liner and the reinforcing fibre, for example, by the application of a suitable protective coating to the liner prior to the wrapping process (if necessary).

7 Design and manufacture

7.1 General

7.1.1 A Type 2 composite tube shall comprise:

a) an internal metal liner with one or two openings along the central axis only, which carries all the longitudinal load and part of the circumferential load;

b) the liner designed to withstand a burst pressure greater than 0,85 of the test pressure of the finished tube.

c) a composite overwrap formed by layers of continuous fibres in a matrix along the parallel portions of the tube sidewall;

d) an optional exterior coating to provide external protection; when this is an integral part of the design it shall be permanent.

7.1.2 A Type 3 composite tube shall comprise:

a) an internal metal liner with one or two openings along the central axis only, which carries part of the longitudinal and circumferential load;

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

c) an optional exterior coating to provide external protection. When this is an integral part of the design it shall be permanent.

7.1.3 A Type 4 composite tube shall comprise:

a) an internal non-load-sharing liner with one or two openings along the central axis only;

b) metallic boss(es) for thread connections, where these are part of the design;

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

d) an optional exterior coating to provide external protection; when this is an integral part of the design it shall be permanent.

7.2 Design submission

7.2.1 The design submission for each new design of tube shall include a detailed drawing, along with documentation of the design including, manufacturing and inspection particulars as detailed in 7.2.2, 7.2.3 and 7.2.4.

The design submission can cover a design family of composite tubes of the same diameter and pressure with different cylindrical lengths from 2× the diameter and up to 5× the length of the representative composite tube and with a water capacity between 450 l and 3 000 l.

7.2.2 Documentation for either the liner or metal boss(es), or both, shall include:

a) material details, including limits of chemical analysis;

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

c) process and specification of manufacture;

d) heat-treatment, temperatures, duration and tolerances, where applicable;

e) inspection procedures (minimum requirements);

f) material properties (including hardness for Type 2 and Type 3 tubes);

g) minimum design burst pressure (for Type 2 and Type 3 tube liners);

h) dimensional details of valve threads;

i) method of sealing boss to liner for Type 4 tubes.

7.2.3 Documentation for the composite overwrap shall include:

a) fibre material, specification and mechanical properties requirements;

b) minimum composite thickness;

c) resin system – main components and resin bath temperature where applicable;

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

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

f) overwrap construction including the number of strands used, number of layers, and layer orientation;

g) curing process, temperatures, duration and tolerances.

7.2.4 Documentation for the composite tube shall include:

a) water capacity in litres;

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

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

d) working pressure, p_w, which shall not exceed 2/3 of the test pressure;

e) test pressure, p_h;

f) allowable range of elastic expansions and permanent expansions, if appropriate, for the design when volumetric expansion test is used (see 9.5.4);

g) maximum developed pressure at 65 °C for specific dedicated gas(es), p_{max};

h) minimum design burst pressure;

i) design life in years (15 years or more);

j) autofrettage pressure and approximate duration, where applicable;

k) tensioning of the fibre at winding, where applicable;

l) mass and manufacturing tolerance;

m) details of components which are permanently attached and form part of the qualified design (neck rings, protective boots etc.).

7.3 Manufacturing

7.3.1 The liner and metal bosses, where incorporated, shall be manufactured in accordance with the manufacturer's design (see 7.2.2).

7.3.2 The composite tube shall be fabricated from a load-sharing or non-load-sharing liner, over-wrapped with layers of continuous fibres in a matrix, applied under controlled conditions to develop the design composite thickness.

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

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

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

7.3.5 If tubes are subjected to a pre-stressing or fibre tensioning during winding to actively change the final stresses in the finished tube, the level of stress shall be as specified in 7.2.4 and levels of stress of tensioning shall be recorded or monitored.