INTERNATIONAL STANDARD

ISO 11515

Second edition
2022-08

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.

8 Type approval procedure

8.1 General

The design submission of each new design of composite tube shall be submitted by the manufacturer to the inspector. The type approval tests detailed in 8.2 shall be carried out on each new design or design variant under the supervision of the inspector.

8.2 Prototype tests

8.2.1 A sufficient number of tubes shall be made available from a single batch to complete the prototype testing or testing of the design variant.

NOTE Additional tubes from the same prototype batch can be made available in case of test equipment failure.

8.2.2 The inspector shall verify that the batch of liners, prior to being wrapped, conforms to the design requirements and are inspected and tested in accordance with 9.1 or 9.3, as appropriate.

8.2.3 The inspector shall verify that the composite material(s), prior to the tubes being wrapped, conform to the design requirements and are tested in accordance with 9.4.

8.2.4 The inspector shall verify that all tubes in the batch produced for new design approval conform to the design submission and are tested in accordance with 9.5. Except for the cases identified in 8.2.5, the inspector shall supervise the tests shown in Table 1. An "A" in the relevant column of Table 1 shows that the test is required for the appropriate tube category. An "O" in the relevant column of Table 1 shows that the test is required for particular designs, materials and uses. The relevant clause for each test describes when the test is required.

Table 1 — Prototype testing for new designs

Design tests with subclause number	Type 2	Type 3	Type 4
8.5.2 Hydraulic proof pressure test, or 8.5.3 Hydraulic volumetric expansion test	A	A	A
8.5.4 Liner burst test	A	A	—
8.5.5 Tube burst test	A	A	A
8.5.6 Ambient temperature cycling test	A	A	A
8.5.7 Environmental cycling test	A	A	A
8.5.8 Flaw test	—	A	A
8.5.9 Blunt impact test	A	A	A
8.5.10 Fire resistance test	A	A	A
8.5.11 Neck strength test	—	—	A
8.5.12 Leak test	—	—	A
8.5.13 Accelerated stress rupture test	O	O	O
8.5.14 Permeability test	—	—	O
8.5.15 Gas cycling test	—	—	A

Key

A : all tube designs tested

O : only required for particular designs, materials and uses

[a] Tubes being used for other tests may be used.

[b] Coating tests can be carried out on sections/domes of tubes as appropriate.

Table 1 *(continued)*

Design tests with subclause number	Type 2	Type 3	Type 4
8.5.16 Coatings test[a] (where applicable)[b]	O	O	O
8.5.17 Salt spray test	O	O	O
8.5.18 Acid environment test	O	O	O
8.5.19 Vacuum test	—	—	O
8.5.20 High velocity impact (gunfire) test	O	A	A
8.5.21 Glass transition temperature test	A	A	A
8.5.22 Resin shear strength test	A	A	A

Key

A : all tube designs tested

O : only required for particular designs, materials and uses

[a] Tubes being used for other tests may be used.

[b] Coating tests can be carried out on sections/domes of tubes as appropriate.

8.2.5 For variations in design from the new design tube as specified in 8.4, it is only necessary to carry out the tests as prescribed in Tables 2 to 4 as appropriate. A tube approval obtained by a reduced series of tests shall not be used as a basis for a second design variant approval with a reduced set of tests (i.e. multiple changes from an approved design are not permitted) although individual test results can be used as applicable (see 8.4.2).

8.2.6 If the results of the verifications and tests according to 8.2.2, 8.2.3 and 8.2.4 as modified by 8.2.5 are satisfactory, the inspector shall issue a type approval certificate. A typical example of such an approval certificate is given in Annex A.

8.2.7 After completion of the tests the tubes shall be destroyed or made incapable of holding pressure.

8.3 New design

8.3.1 This subclause specifies when a composite tube is a new design for the purposes of this document. Subclause 8.4 specifies when a composite tube is a design variant.

8.3.2 A new tube design requires full type approval testing. A tube shall be considered to be of a new design compared to an existing approved design if the following applies.

a) It is manufactured in a different factory. A relocation of a factory does not require a new tube design approval provided all materials, equipment and procedures remain the same as for the original design approval.

b) It is manufactured by a process that is significantly different from the process used in the design type approval. A significant change is regarded as a change that would have a measurable change in the performance of either the liner or the finished tube, or both. The inspector shall determine when a change in process or design or manufacture is significantly different from the original qualified design.

c) The nominal outside diameter has changed by more than 50 % from the qualified design.

d) The composite overwrap materials are significantly different from the qualified design, for example, different resin system or fibre type.

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

8.3.3 A tube shall also be considered to be of a new design compared to an existing approved design if the following applies.

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

b) The liner material properties are outside the original design limits.

8.4 Design variants

8.4.1 For tubes similar to an approved design, a reduced type approval testing programme is allowed. A tube shall be considered to be a design variant if the following applies.

a) The outside diameter has changed by 50 % or less.

b) The autofrettage pressure has changed by more than 5 %.

c) Either the base profile or the base thickness of the liner, or both, has changed relative to the tube diameter and minimum wall thickness.

d) There is a change in the design test pressure up to and including 60 %. Where a tube will be used and marked for a lower test pressure than that for which the design approval has been given, it is not deemed to be of a new design or design variant.

e) When changes in diameter or pressure are made, the structural wall elements shall operate at the same, or lower nominal stress levels as the original design (e.g. if pressure or diameter increase, the wall thickness has to increase proportionally).

f) The minimum composite thickness has changed by more than 5 % for reasons other than a change in test pressure or diameter.

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

h) When equivalent matrix materials are used:

   1) New matrix materials are equivalent if they are from the same chemical family (epoxy, vinyl ester or polyester) and the minimum requirements of interlaminar shear testing are achieved and the new matrix material has a T_g equal to or higher than the system being replaced.

      Epoxy, vinyl ester and polyester systems are not chemically equivalent to each other.

   2) Where a new equivalent matrix material has been prototype tested for an existing design, then all the manufacturer's existing prototype tested designs are regarded as prototype tested with the new matrix material without the need for any additional prototype testing.

i) When equivalent overwrapping fibres are used:

   1) Equivalent fibres are manufactured from the same nominal raw materials, using the same process of manufacture and having the same physical structure and the same nominal physical properties, and where the average tensile strength and modulus is within ±5 % of the fibre properties in an approved tube design. Carbon fibres made from the same precursor can be equivalent. Aramid, carbon and glass fibres are not equivalent.

   2) Where a new equivalent fibre has been prototype tested for an existing design, then all the manufacturer's existing prototype tested designs are regarded as prototype tested with the new fibre without the need for any additional prototype testing.

j) When an equivalent liner is used:

   1) Equivalent liners are manufactured from the same nominal raw materials, using the same process of manufacture. They have nominal physical properties that are within ±5 % of physical properties in the approved tube design and fulfil the requirements of the relevant standard.

2) Where a new equivalent liner has been prototype tested for an existing design, then all the manufacturer's existing prototype tested designs are regarded as prototype tested with the new liner, without the need for any additional prototype testing.

k) When a Type 4 tube design has only a different thread compared to an approved design, the neck strength test, in accordance with 8.5.11, shall be carried out.

l) The design or the boss material or method of joining the neck boss to the liner has changed.

8.4.2 A tube approval by a reduced series of tests (a design variant) shall not be used as a basis for a second design variant approval with a reduced set of tests (i.e. multiple changes from an approved design are not permitted). If a test has been conducted on a design variant (A) that falls within the testing requirements for a second variant (B) then the result for (A) can be applied to the new design variant (B) test programme. However, design variant (A) cannot be used as the reference for determining the testing required for any new design variant.

8.4.3 Where a design variant involves more than one parameter change, all the tests required by those parameter changes shall be performed once only.

8.4.4 The inspector shall determine the level of reduced testing if not defined in Tables 2, 3 or 4 for the appropriate tube category, but a fully approved design shall always be used as a reference for the new design variant (new design variants shall not be approved by reference only to a previous design variant).

Table 2 — Type approval tests for Type 2 tubes

Test number	Test	New design	Design variant									
			Nominal diameter		Equivalent liner	Minimum liner thickness	Test pressure		Minimum composite thickness	Equivalent fibre	Equivalent matrix	Auto-frettage
			≤20 %	> 20 % ≤ 50 %		>10 %	$p_h \leq 20$ %	20 % < p_h ≤ 60 %	>5 %			>5 %
9.1	Liner material test	X			X	X						
9.5	Composite material tests	X								X	X	
8.5.2/8.5.3	Hydraulic pressure test	X	X	X	X	X	X	X	X	X		X
8.5.4	Liner burst test	X	X	X	X	X	X[f]	X[f]				
8.5.5	Tube burst test	X	X	X	X	X	X	X	X	X	X	X
8.5.6	Ambient cycle test	X	X	X	X	X	X	X	X	X	X	X
8.5.7	Environmental cycle test	X										
8.5.9	Blunt impact test	X		X[a]	X	X[b]		X		X		
8.5.10	Fire resistance test	X		X		X[b]		X				
8.5.13	Stress rupture test	X		X					X	X		
8.5.17	Salt spray test[c]	X			X						X	
8.5.18	Acid environment test[d]	X				X		X	X			
8.5.20	High velocity impact test[e]	X						X				
8.5.21	Glass transition temperature test	X									X	
8.5.22	Resin shear strength test	X									X	

[a] The test shall be conducted for a reduction in diameter only.

[b] The test shall be conducted on tubes for a reduction in the liner thickness of 10 % or more.

[c] The test shall be conducted on tubes with steel liners.

[d] The test shall be conducted on tubes with load bearing glass fibre.

[e] The test shall be conducted on tubes intended for military applications only.

[f] The test is not required if a burst test has been conducted on the design previously.

Table 3 — Type approval tests for Type 3 tubes

Test number	Test	New design	Design changes									
			Nominal diameter		Equivalent liner	Minimum liner thickness	Test pressure		Minimum composite thickness	Equivalent fibre	Equivalent matrix	Auto-frettage
			≤20 %	> 20 % ≤ 50 %		>10 %	$p_h \leq 20$ %	20 % < p_h ≤ 60 %				>5 %
9.1	Liner material test	X			X	X						
9.5	Composite material tests	X								X	X	
8.5.2/8.5.3	Hydraulic pressure test	X	X	X	X	X	X[a]	X	X	X		X
8.5.4	Liner burst test	X	X	X	X	X						
8.5.5	Tube burst test	X	X	X	X	X	X[a]	X	X	X	X	X
8.5.6	Ambient cycle test	X	X	X	X	X	X[a]	X	X	X	X	X
8.5.7	Environmental cycle test	X										
8.5.8	Flaw test	X						X				
8.5.9	Blunt impact test	X		X[b]		X[a]		X		X		
8.5.10	Fire resistance test	X		X		X[a]		X				
8.5.13	Stress rupture test	X		X				X	X	X		
8.5.17	Salt spray test[c]	X			X						X	
8.5.18	Acid environment test[d]	X						X	X			
8.5.20	High velocity impact test	X						X				
8.5.21	Glass transition temperature test	X									X	
8.5.22	Resin shear strength test	X									X	

[a] The tests shall be conducted on tubes for a reduction in the liner thickness of 20 % or more.

[b] The test shall be conducted for a reduction in diameter only.

[c] The test shall be conducted on tubes with steel liners only.

[d] The test shall be conducted on tubes with load bearing glass fibre.

Table 4 — Type approval tests for Type 4 tubes

Test number	Test	New design	Design changes									
			Nominal diameter		Equivalent liner	Minimum liner thickness	Test pressure		Minimum composite thickness	Neck boss	Equivalent matrix	Equivalent fibre
			≤20 %	>20 % ≤50 %		>105 %	$p_h \leq 20$ %	20 % < $p_h \leq$ 60 %				
9.1	Liner material test	X			X	X						
9.5	Composite material tests	X							X		X	X
8.5.2/8.5.3	Hydraulic pressure test	X	X	X	X	X	X[a]	X	X	X		X
8.5.5	Tube burst test	X	X	X	X	X	X[a]	X	X	X	X	X
8.5.6	Ambient cycle test	X	X	X	X	X	X[a]	X	X	X	X	X
8.5.7	Environmental cycle test	X								X		
8.5.8	Flaw test	X						X				
8.5.9	Blunt impact test	X		X				X				X
8.5.10	Fire resistance test	X		X				X				
8.5.11	Neck strength test	X								X		
8.5.12	Leak test	X								X		
8.5.13	Stress rupture test	X		X				X	X	X		X
8.5.14	Permeability	X		X		X		X		X		
8.5.15	Gas cycling test	X										
8.5.18	Acid environment test[b]	X				X		X	X		X	
8.5.20	High velocity impact test	X						X				
8.5.19	Vacuum test	X								X		
8.5.21	Glass transition temperature test	X									X	
8.5.22	Resin shear strength test	X									X	

[a] The test shall be conducted on tubes for a reduction in the liner thickness of 20 % or more.

[b] The test shall be conducted on tubes with load bearing glass fibre.

[c] The test shall be conducted for a reduction in diameter only.

8.5 Type approval test procedures and criteria

8.5.1 General

The manufacturer can conduct more than one of the type approval tests on a particular tube with the agreement of the inspector.

Each completed tube shall be subjected to either a hydraulic proof test (in accordance with 8.5.2) or a volumetric expansion test (in accordance with 8.5.3) at the design test pressure specified in 7.2.4.

8.5.2 Hydraulic proof pressure test

8.5.2.1 Procedure

When carrying out the pressure test, a suitable fluid (e.g. normally water) shall be used as the test medium. This test requires that the pressure in the tube be increased gradually and regularly until the test pressure, p_h, is reached. The test pressure shall be held 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. Adequate safety precautions shall be taken during the test.

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

The deviation limit on attaining test pressure shall be: $(p_h + 3)\%$ or $(p_h {}^{+10}_{0})$ bar whichever is lower. Pressure gauges with the appropriate accuracy shall be used.

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

Where tubes are subjected to autofrettage, the hydraulic proof pressure test may be part of, or immediately follow, the autofrettage process.

8.5.2.2 Criteria

The tube shall be rejected if there are leaks, if it has failed to hold pressure or if there are visible permanent deformation after the tube is depressurized.

NOTE Cracking of resin is not necessarily a sign of permanent deformation.

8.5.3 Hydraulic volumetric expansion test

8.5.3.1 Procedure

When carrying out the pressure test, a suitable fluid (normally water) shall be used as the test medium. This test requires that the pressure in the tube to be increased gradually and regularly until the test pressure, p_h, is reached. The tube test pressure shall be held 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. Adequate safety precautions shall be taken during the test.

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

The deviation limit on attaining test pressure shall be: $(p_h + 3)\%$ or $(p_h {}^{+10}_{0})$ bar whichever is lower. Pressure gauges with the appropriate accuracy shall be used.

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

The total volumetric expansion of each tube under the test pressure, p_h, and the permanent volumetric expansion of the tube after the pressure is released shall be recorded. The elastic expansion (i.e. total expansion less permanent expansion) under test pressure shall be established for each tube.

Where tubes are subjected to autofrettage, the hydraulic volumetric expansion pressure test may be part of or immediately follow the autofrettage process.

8.5.3.2 Criteria

The tube shall be rejected if either:

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

b) it shows a permanent expansion (i.e. volumetric expansion after the pressure has been released) in excess of 5 % of the total expansion.

NOTE Cracking of resin is not necessarily a sign of permanent deformation.

8.5.4 Liner burst test

8.5.4.1 General

This test is required for liners in Type 2 and Type 3 tubes.

8.5.4.2 Procedure

One tube liner shall be tested hydraulically to destruction at a rate of no more than 10 bar/s. The test shall be carried out under ambient conditions.

Parameters to monitor and record are:

a) burst pressure;

b) number of pieces;

c) description of failure;

d) pressure/time curve.

8.5.4.3 Criteria

For Type 2 tubes, the liner burst pressure shall be equal to or greater than 0,85 of the tube design test pressure, p_h, and shall be not less than the minimum liner design burst pressure, specified in the design submission (see 7.2.2). Failure shall initiate in the liner side wall and the liner shall remain in one piece.

For Type 3 tubes, the burst pressure shall be not less than the minimum design burst pressure, specified in the design submission (see 7.2.2). Failure shall initiate in the liner side wall and the liner shall remain in one piece.

8.5.5 Tube burst test

8.5.5.1 Procedure

Three tubes shall be tested hydraulically to destruction by pressurizing at a rate of no more than 10 bar/s. The test shall be carried out under ambient conditions. Prior to the test, it shall be ensured that no air is trapped within the system.

Parameters to monitor and record are:

a) burst pressure;

b) description of failure;

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

8.5.5.2 Criteria

8.5.5.2.1 Type 2 tubes

The burst pressure, p_b, for tubes with carbon fibre reinforcement shall be equal to or greater than the minimum design burst pressure and not less than the test pressure, p_h, ×1,67 of the composite tube design.

The burst pressure, p_b, for tubes with aramid fibre reinforcement, or a mixture of fibres where aramid is the main structural component, shall be equal to or greater than the minimum design burst pressure and shall be not less than the test pressure, p_h, ×2,0 of the composite tube design.

The burst pressure, p_b, for tubes with glass fibre reinforcement, or a mixture of fibres where glass fibre is the main structural component, shall be equal to or greater than the minimum design burst pressure and shall be not less than the test pressure, p_h, ×2,0 of the composite tube design.

Failure shall initiate in the tube side wall and the tube liner shall remain in one piece.

8.5.5.2.2 Type 3 and Type 4 tubes

The burst pressure, p_b, for tubes with carbon fibre reinforcement shall be equal to or greater than the minimum design burst pressure and shall be not less than the test pressure, p_h, × 2,00, of the composite tube design.

The burst pressure, p_b, for tubes with aramid fibre reinforcement, or a mixture of fibres where aramid is the main structural component, shall be equal to or greater than the minimum design burst pressure and shall be not less than the test pressure, p_h, × 2,10 of the composite tube design.

The burst pressure, p_b, for tubes with glass fibre reinforcement, or a mixture of fibres containing glass fibre as the main structural component, shall be equal to or greater than the minimum design burst pressure and shall be not less than the test pressure, p_h, × 2,43 of the composite tube design.

8.5.6 Ambient cycle test

8.5.6.1 General

Where a tube is intended for use only with one or more specific gases the design can be designated for dedicated gas use. The gases permitted in the tube shall be identified clearly on the tube label (see 10.2). It is recommended that no air is trapped within the system prior to the test.

8.5.6.2 Procedure

Two tubes shall be subjected to a hydraulic pressure cycle test to test pressure, p_h, for unspecified gas service or maximum developed pressure at 65 °C, p_{max}, for the dedicated gas which has the greatest developed pressure.

The test shall be carried out using a non-corrosive fluid under ambient conditions, subjecting the tubes to successive reversals at an upper cyclic pressure that is equal to the hydraulic test pressure, p_h, or maximum developed pressure at 65 °C, p_{max}, as appropriate. For a tube with two openings, the pressure sensor shall be fitted at the opposite end from the pressurization inlet.

The value of the lower cyclic pressure shall not exceed 10 % of the upper cyclic pressure but shall have an absolute maximum of 30 bar. The frequency of reversals of pressure shall not exceed 5 cycles per min. The temperature on the outside surface of the tube shall not exceed 50 °C during the test.

Parameters to monitor and record are:

a) temperature of the tube;

b) number of cycles achieving upper cyclic pressure;

c) minimum and maximum cyclic pressures;

d) cycle frequency;

e) test medium used;

f) mode of failure, if appropriate.

8.5.6.3 Criteria

The tubes shall withstand N pressurization cycles to test pressure, p_h, or N_d pressurization cycles to maximum developed pressure, p_{max}, without failure by burst or leakage

where

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

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

y is the number of years of design life; y shall be a whole number which is not less than 15 years.

The test shall continue to a total of 24 000 cycles or 48 000 cycles as shown in Table 5, or until the tube fails by leakage, whichever is the sooner. In either case, the tube shall be deemed to have passed the test. However, if failure during this second part of the test is by bursting, then the tube shall have failed the test.

Table 5 — Criteria for ambient cycle test

	First part of the test	Second part of the test
Number of cycles	0 to N	N to $2N$ but $2N$ no more than 24 000
	0 to N_d	N_d to $2N_d$ but $2N_d$ no more than 48 000
Criteria	No leakage/burst equals a pass	
	No leakage or burst	Leakage equals a pass
	Pass first part	Burst equals a fail

8.5.7 Environmental cycle test

8.5.7.1 General

When the vacuum test (see 8.5.19) is performed, the vacuum-tested tube shall be used for the environmental cycle test. When the vacuum test is not performed, a warning shall be permanently marked on the tube label (see 10.2).

The tests in 8.5.7 will be performed in an environmental chamber.

8.5.7.2 Procedure

One tube, as-wrapped and without paint or removable protective coating on the composite material, shall be tested as follows. Alternatively, a representative tube can be tested with the same diameter as the prototype tube but with a cylindrical length of at least twice the diameter of the tube to be tested. Wrapping pattern of the subscale tube shall be representative of the prototype tube.

Condition the tube and contained hydraulic pressurizing medium for 48 h at atmospheric pressure, at a temperature between 60 °C and 70 °C and at a relative humidity greater than or equal to 90 %. The intent of this requirement can be met by spraying with a fine spray or mist of water in a chamber held between 60 °C and 70 °C.

The hydraulic pressurizing medium external to the tube under test shall commence the cycle testing at ambient temperature. Hydraulically apply 5 000 cycles from a pressure less than 10 % of the working pressure to 2/3 of the test pressure, p_h. The temperature on the outside surface of the tube shall be maintained at between 60 °C and 70 °C by regulating the environmental chamber and the cycling frequency. The cycling frequency shall not exceed 10 cycles/min.

Release the pressure and stabilize the tube at 20 °C approximately.

Stabilize the tube and the contained pressurizing medium until the temperature is between −40 °C and −50 °C. The hydraulic pressurizing medium external to the tube under test shall commence the cycle testing at ambient temperature. Apply 5 000 cycles from a pressure less than 10 % of working pressure to 2/3 of the test pressure, p_h. The tube skin temperature shall be maintained at between −40 °C and −50 °C by regulating the environmental chamber and the cycling frequency. The fluid shall also be selected to ensure that it functions at the temperatures specified in the various cycle tests.

Release the pressure and stabilize the tube at approximately 20 °C.

Type 4 tubes shall be subjected to the leak test (see 8.5.12).

On completion of these tests, the tube shall be subjected to the burst test (see 8.5.5).

Parameters to monitor and record are:

a) temperatures during each part;

b) humidity during the first part of test;

c) test medium used;

d) number of cycles, achieving upper cyclic pressure, at each stage;

e) minimum and maximum cyclic pressures;

f) cycle frequency;

g) parameters specified in 8.5.5.

8.5.7.3 Criteria

Type 4 tubes shall pass the leak test (8.5.12).

The burst pressure, p_b, shall be not less than 85 % of the minimum design burst pressure.

8.5.8 Flaw test

8.5.8.1 General

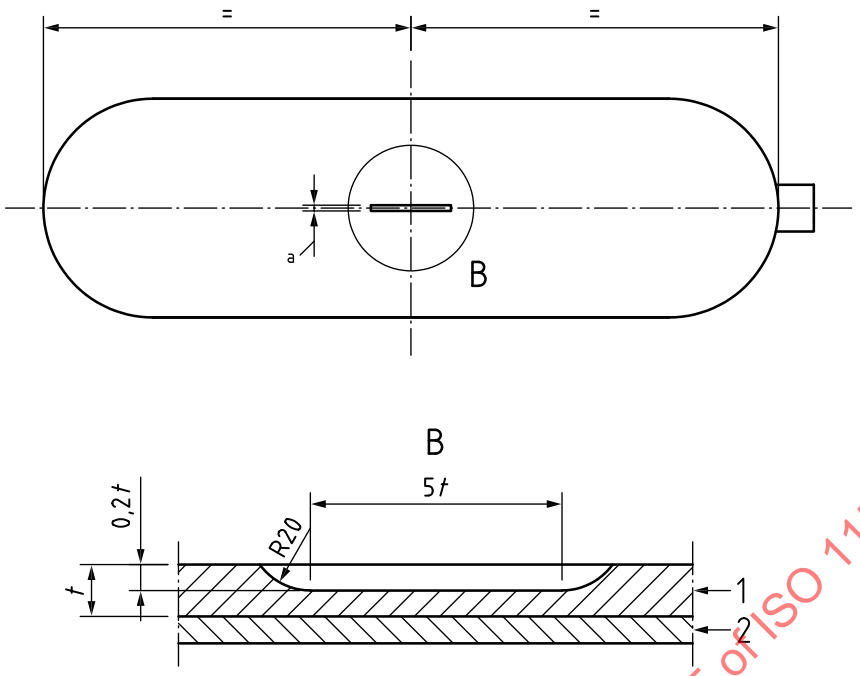
This test is required for all Type 3 and Type 4 tubes.

One tube shall be tested in accordance with the requirements of 8.5.8.2.

A representative tube can be tested with the same diameter as the prototype tube but with a cylindrical length of at least twice the diameter. Wrapping pattern of the subscale tube shall be representative of the actual tube.

8.5.8.2 Procedure

One longitudinal flaw is cut in the mid-length of the cylindrical wall of the tube. The flaw shall be made with a cutter blade width of 1 mm to 3 mm to a depth equal to 20 % of the nominal composite thickness, t, and to a length between the centres of the cutter equal to five times the composite thickness (see Figure 1).



Key

1 wrap

2 liner

[a] 1 mm wide.

Figure 1 — Flaw test procedure

The tube shall be subjected to the ambient cycle test specified in 8.5.6, but the upper cyclic pressure shall be 2/3 of the test pressure, p_h, and the test shall be suspended after 3 000 cycles if the tube has not failed.

The flawed tube used for the cycle test is permitted to be used for the burst test in 8.5.5.

Parameters to monitor and record are:

a) dimensions of flaws;

b) temperature of the tube;

c) number of cycles achieving upper cyclic pressure;

d) minimum and maximum cyclic pressures;

e) cycle frequency;

f) test medium used;

g) mode of failure, if appropriate.

At the completion of the test, the tube shall be made unserviceable.

8.5.8.3 Criteria

The composite tube shall withstand 3 000 pressure cycles to 2/3 of the test pressure, p_h, without leakage or burst.

8.5.9 Blunt impact test

8.5.9.1 Procedure

For Type 2 tubes, one empty tube, and if necessary, a second empty tube, shall be subjected to two impacts:

a) one at the tube sidewall midway between the ends;

b) one at the termination of the overwrap near the domes.

For Type 3 and Type 4 tubes, one empty tube and, if necessary, a second empty tube shall be subjected to two impacts:

a) one at the tube sidewall midway between the ends;

b) one at an angle of 45° to strike the shoulder of the tube (mid arc length at the dome).

See Figure 2.

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

The tube shall be secured to ensure it does not move during the impact. The impactor shall be made from a steel bar and have a diameter of between 110 mm and 120 mm.

In test one, an impactor with a potential energy of 1 200 J shall strike the tube at the positions identified above.

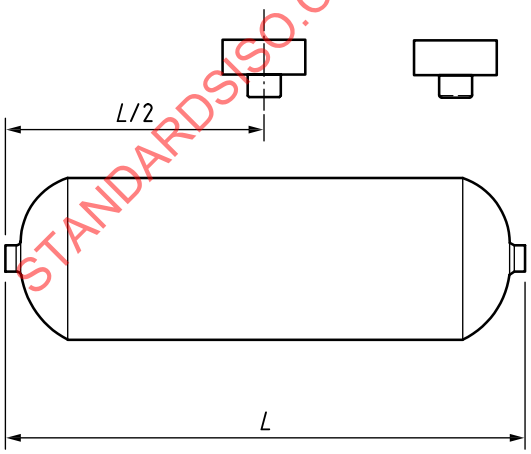
In test two (if necessary), an impactor with a potential energy of 488 J shall strike the tube at the positions identified above.

The tube shall then be subjected to the appropriate ambient cycle test as described in 8.5.6.

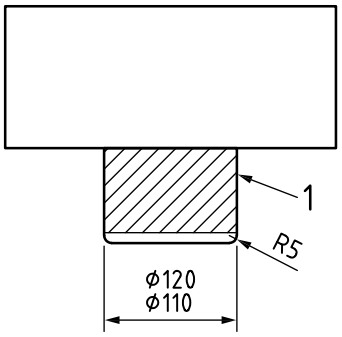
Parameters to monitor and record are:

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

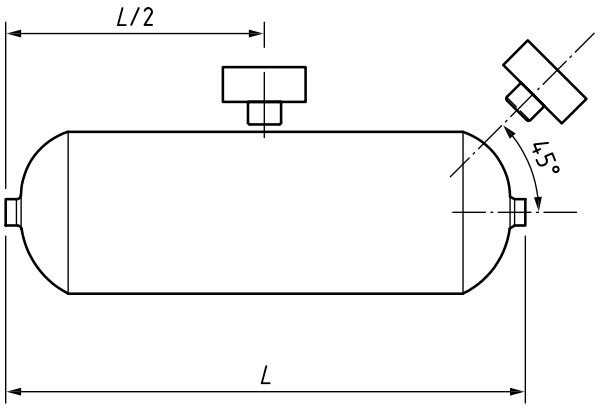
b) parameters specified in 8.5.6.



a) Type 2 tubes



b) Example of impactor



c) Type 3 and Type 4 tubes

Key

1 steel bar

L length of tube

Figure 2 — Blunt impact test procedure

8.5.9.2 Criteria

The tubes shall withstand 3 000 pressurization cycles at maximum developed pressure, p_{max}, without failure by burst or leakage. The test shall continue for additional cycles representing its specified lifetime, or until the tube fails by leakage, whichever is the sooner. In either case, the tube shall be deemed to have passed the test. However, if failure during this second part of the test is by burst, then the tube shall have failed the test.

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 in the qualification report and on the label (see 7.2.1).

If the tube does not pass the blunt impact test at this level, 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 qualification report and on the label (see 7.2.1).

A tube that does not pass at an energy level of 488 J shall not be approved.

NOTE In cases where a tube passes the Level 1 test but fails the Level 2 test, the manufacturer can inform the customer that a risk assessment can be needed, depending on the intended application.

8.5.10 Fire resistance test

8.5.10.1 General

The purpose of the test is to demonstrate that the tube design shall either:

a) not burst when exposed to a test fire when using a specified pressure relief device (PRD); or

b) withstand a minimum specified time in the test fire when a PRD is not to be used in service; the minimum specified time shall not be less than 5 min.

This test is intended to demonstrate the performance of a single tube in a fire. If a tube or multiple tubes are used in a system, and particularly if a PRD is not used, the performance of the fire protection of the system as a whole in preventing a tube rupture should be considered by the responsible system designer (e.g. the MEGC or trailer designer).

8.5.10.2 Procedure

8.5.10.2.1 Set-up 1: Tube fitted with the specified valves and PRDs to be used in service

When the tube is fitted with the specified valves and PRDs to be used in service, the specification of the valve and PRDs shall be marked on the design drawing and the approval certificate.

One tube shall be fitted with specified valves and PRDs to be used in service. The tube shall be charged with air or nitrogen or the gas intended for use to the working pressure ($p_h \times 2/3$).

The tube shall be placed in a horizontal position with the centre of the fire at the mid-point of the tube and with the lowest part of the tube approximately 0,1 m from the top of fire source. Surface temperatures shall be monitored by three thermocouples equally spaced along the length of the fire and shielded from direct flame impingement with metallic shielding of a minimum 0,4 mm thickness. Thermocouple temperatures and the tube pressure shall be recorded at intervals of every 30 s or less during the test.

A uniform fire source of 1,65 m length shall be used that is capable of enveloping the entire diameter of the tube, when in the horizontal position, and producing a temperature ≥590 °C measured within 4 min on the bottom surface of the tube.

The timing of the fire test shall start when at least one thermocouple registers a temperature of 590 °C and at least two thermocouples are required to register a temperature ≥590 °C for the remainder of the test.

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 pollution concerns.

The tube shall be exposed to the fire until it has vented to a pressure less than 7 bar.

The parameters to monitor and record are:

a) type and characteristics of the pressure relief device(s) and valve(s);

b) initial pressure;

c) location of leak;

d) temperature;

e) time.

8.5.10.2.2 Set-up 2: Tube not fitted with specified valves and PRDs to be used in service

When the tube is not fitted with specified valves and PRDs to be used in service, the tube shall be fitted with a method to safely release the gas. The tube shall be charged with air or nitrogen or the gas intended for use to the working pressure ($p_h \times 2/3$).

The tube shall be placed in a horizontal position with the centre of the fire at the mid-point of the tube and with the lowest part of the tube approximately 0,1 m from the top of fire source.

Surface temperatures shall be monitored by three thermocouples equally spaced along the length of the fire and shielded from direct flame impingement with metallic shielding of a minimum 0,4 mm thickness. Thermocouple temperatures and the tube pressure shall be recorded at intervals of every 30 s or less during the test.

A uniform fire source of 1,65 m length shall be used that is capable of enveloping the entire diameter of the tube, when in the horizontal position, and producing a temperature ≥590 °C, measured within 2 min on the bottom surface of the tube.

The timing of the fire test shall start when at least one thermocouple registers a temperature of 590 °C and at least two thermocouples are required to register a temperature ≥590 °C for the remainder of the test.

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 pollution concerns.

The tube shall be exposed to the fire for the time specified by the tube manufacturer, which shall be at least 5 min at a temperature ≥590 °C. Any pressure remaining after the test is completed shall be safely vented.

The parameters that shall be monitored and recorded are:

a) initial pressure;

b) location of leak, if appropriate;

c) temperature;

d) time.

8.5.10.3 Criteria

a) For tubes intended to be fitted with specified pressure-relief devices, the tube shall vent through the pressure-relief devices. This test shall be repeated if another design of pressure-relief device is specified and used.

b) Tubes without a specified pressure-relief device shall not rupture before the time specified by the manufacturer and not less than 5 min from the start of the fire test. Tubes can leak through the cylindrical wall, valves (if fitted) or other surfaces.

For all tubes the manufacturer shall provide the system designer with this fire performance data to enable them to carry out a risk assessment of the fire protection for the system with the objective to prevent tube rupture in service.

8.5.11 Neck strength test

8.5.11.1 General

This test is required for all Type 4 designs. One tube shall be tested.

A representative tube can be tested with the same diameter as the prototype tube but with a cylindrical length of at least twice the diameter. Wrapping pattern of the subscale tube shall be representative of the actual tube.

8.5.11.2 Procedure

The body of the tube shall be held in a manner to prevent it rotating. The tube shall be fitted with a corresponding valve or suitable plug and tightened to 110 % of the maximum torque recommended in ISO 13341 for either the relevant liner material or boss material, or both, or as recommended by the manufacturer on the design drawing.

Parameters to monitor and record are:

a) type of valve/plug material;

b) valving procedure;

c) applied torque.

The valve or plug shall be removed after the first installation and the neck thread and boss inspected. The valve shall then be re-installed as specified above.

The tube shall then be subjected to the leak test specified in 8.5.12.

8.5.11.3 Criteria

There shall be no permanent visible damage to any combination of the boss, liner and composite interfaces.

A leakage rate greater than 2 bubble/min in the bubble leak test or leakage greater than 5×10^{-3} mbar·l/s of gaseous helium (or equivalent) shall constitute a failure of the test.

8.5.12 Leak test

8.5.12.1 General

This test is required for all Type 4 tubes.

8.5.12.2 Procedure

Leak testing shall be conducted on the finished tube.

Acceptable methods for leakage testing include bubble testing using dry air or gas or measurement of trace gases using a mass spectrometer, portable gas detector or other suitable technique.

Leak testing of completed tubes shall be performed at 2/3 times test pressure, p_h.

8.5.12.3 Criteria

Leakage greater than 2 bubble/min in the bubble leak test or leakage greater than 5×10^{-3} mbar·l/s of gaseous helium (or equivalent) shall constitute a failure of the test.

8.5.13 Accelerated stress rupture test

8.5.13.1 General

This test shall be conducted only on tubes where glass or aramid fibre has a load-sharing application.

One tube, as-wrapped and without paint or removable protective coating on the composite material, shall be tested as follows. Alternatively, a representative tube can be tested with the same diameter as the prototype tube but with a cylindrical length of at least twice the diameter of the tube to be tested. The wrapping pattern of the subscale tube shall be representative of the prototype tube.

8.5.13.2 Procedure

For a design life of up to 20 years, one tube shall be hydraulically pressurized to test pressure at 85 °C, and shall be maintained at this pressure and at a temperature of 85 °C for 1 000 h.

For a design life equal to or greater than 20 years, one tube shall be hydraulically pressurized to test pressure at 85 °C, and shall be maintained at this pressure and at a temperature of 85 °C for 2 000 h.

The tube shall be then be subjected to the burst test (8.5.5).

Parameters to monitor and record are:

a) temperature at least twice a day;

b) tube pressure at least twice a day;

c) burst pressure.

8.5.13.3 Criteria

To successfully pass the test, the tube shall complete the 1 000 h or 2 000 h hold at 85 °C without rupture, and the burst pressure shall exceed 85 % of the minimum design burst pressure.

8.5.14 Permeability test

8.5.14.1 General

This test is required for all Type 4 tubes. A representative tube can be tested with the same diameter as the prototype tube but with a cylindrical length of at least twice the diameter of the tube to be tested. The wrapping pattern of the subscale tube shall be representative of the prototype tube.

8.5.14.2 Procedure

One finished tube shall be filled with a suitable test gas to working pressure, placed in an enclosed sealed chamber at a temperature of 20 °C ± 5 °C until the permeation rate reaches a steady-state as recorded over 50 h. The test duration is not required to exceed 500 h.

NOTE Suitable test gases include the gas to be contained, hydrogen, or nitrogen mixtures with hydrogen or helium.

Parameters to monitor and record are:

a) test gas used;

b) permeation rate;

c) temperature of the test chamber.

8.5.14.3 Criteria

The permeation rate shall be less than the equivalent of six normal millilitres of hydrogen gas per hour per litre water capacity. Equivalent permeation rates, using different gases or mixtures, can be calculated by using the square root of the ratio of the molecular weights and with consideration of reference temperature and the gas or mixtures. See Annex D.

8.5.15 Gas cycle test

8.5.15.1 General

This test is required for all Type 4 tubes. A representative tube can be tested with the same diameter as the prototype tube but with a cylindrical length of at least twice the diameter of the prototype. The wrapping pattern of the subscale tube shall be representative of the prototype tube.

Special consideration shall be given to safety when conducting this test. Prior to conducting this test, the tube to be tested shall have successfully passed the test requirements of the leak test (see 8.5.12) and the hydrostatic proof test (see 8.5.2).

Tubes that are intended to contain air in service shall use air for this test. Tubes that are intended to contain hydrogen in service shall use hydrogen for this test. If the tubes are intended for general gas service, then air or nitrogen or hydrogen may be used. If the tube is not tested with air or hydrogen, then it is not approved to contain air or hydrogen as applicable.

8.5.15.2 Procedure

One tube shall be tested as follows:

a) The tube shall be filled with air, nitrogen or hydrogen as appropriate.

b) Fill the tube with the test gas to $2/3 \times p_h$ at a pressurization rate of 40 bar/min or less.

c) Hold the tube at the pressure described in b) in ambient conditions for 20 h.

d) After 20 h, open the tube valve and vent the tube until empty.

e) Allow 4 h for the tube to stabilize at room temperature.

f) Repeat steps a) through e) until 30 cycles have been completed.

After 30 cycles the valve shall be removed, and the condition of the liner and liner/end boss interface shall be visually inspected for evidence of any deterioration, such as blistering, cracking or electrostatic discharge. If there is visible degradation of the liner (such as, but not limited to, blistering, cracking or delamination) the condition shall be recorded.

If there is degradation of the liner after 30 cycles, the tube shall be tested with the leak test in accordance with 8.5.12 after completion of the thirtieth cycle. If this tube passes the leak test, then it shall be subjected to the permeability test in accordance with 8.5.14.

Parameters to monitor and record are:

a) test gas used;

b) visual appearance of the liner after 30 pneumatic cycles;

c) results of the leak test, if applicable;

d) results of the permeability test, if applicable.

8.5.15.3 Criteria

A tube that has completed 30 pneumatic cycles as described in 8.5.15.2 with no visible evidence of deterioration, such as cracking, blistering or evidence of electrostatic discharge, has successfully passed the test.

A tube that has completed 30 pneumatic cycles and shows visible evidence of progressive deterioration, such shall be subjected to the leak test (see 8.5.12) and the permeability test (see 8.5.14). If the tube successfully completed the leak test and permeability test, then it will have successfully passed the test.

8.5.16 Coatings test

Where coatings are specified as part of the design, they shall be evaluated by the following standards or equivalent tests:

a) adhesion testing, in accordance with ISO 4624:2016, using method A or B as applicable – the coating shall exhibit an adhesion rating of either 4A or 4B, as applicable;

b) flexibility, in accordance with ASTM D522, using test method B with a 12,7 mm (0,5 in) mandrel at the specified thickness at –20 °C – samples for the flexibility test shall be prepared in accordance with ASTM D522-93 – there shall be no visually apparent cracks;

c) impact resistance, in accordance with ASTM D2794 – the coating at room temperature shall pass a forward impact test of 18 J (13,3 ft lbs);

d) chemical resistance, in accordance with ASTM D1308, except that the tests shall be conducted using the open spot test method and 100 h exposure to a 30 % sulfuric acid solution (battery acid

with a specific gravity of 1,219) and 24 h exposure to a polyalkalene glycol (e.g. brake fluid) – there shall be no evidence of lifting, blistering or softening of the coating and the adhesion shall meet a rating of 3 when tested in accordance with ISO 4624;

e) minimum 1 000 h exposure, in accordance with ASTM G154 – there shall be no evidence of blistering and adhesion shall meet a rating of 3 when tested in accordance with ISO 4624; the maximum gloss loss allowed is 20 %;

f) minimum 500 h exposure in accordance with ISO 9227 – undercutting shall not exceed 2 mm at the scribe mark, there shall be no evidence of blistering and adhesion shall meet a rating of 3 when tested in accordance with ISO 4624;

g) resistance to chipping at room temperature, in accordance with ASTM D3170 – the coating shall have a rating of 7A or better and there shall be no exposure of the substrate.

8.5.17 Salt spray test

8.5.17.1 General

This test is required for composite tubes with steel liners. The testing shall be performed in accordance with the requirements of ISO 9227.

8.5.17.2 Procedure

For tubes with steel liners, the test ring shall be cut from one of the prototype tubes or tubes used as the representative production batch. This shall use the same material/composite wrap combination.

A sample test piece shall be taken from one end of the tube, have a parallel length of at least 300 mm and include a dome.

For the Type 2 tubes, the tube dome shall be in the final condition intended for service (e.g. coated). The test ring shall be produced by the same method and have the same liner/composite fibre and resin.

Each test ring shall have all exposed fibres around the cut edges sealed and protected by the same resin used in the manufacture of the prototype tubes. The salt spray test shall be carried out as described in ISO 9227:2017, Clauses 8 to 12, using the neutral salt spray (described in Table 2) and with an exposure time of at least 240 h.

After testing has been completed, the composite material shall be removed from the liner using a method which does not damage or change the surface of the liner's external surface.

The liner's external surface and that of the composite in contact with liner shall then be examined for signs of corrosion.

8.5.17.3 Criteria

The metal surface shall not show pitting greater than 10 % of the liner wall thickness. Surface rust bloom is acceptable.

8.5.18 Acid environment test

8.5.18.1 General

This test is required for all composite tubes using either all glass fibre reinforcement or glass fibre to provide some of the load sharing in a hybrid design. A representative tube can be tested with the same diameter as the prototype tube but with a cylindrical length of at least twice the diameter. Wrapping pattern of the subscale tube shall be representative of the actual tube.

8.5.18.2 Procedure

One finished tube shall be hydraulically pressurized to 130 % of working pressure and a 150 mm diameter area on the tube surface exposed for 100 h to a 30 % sulfuric acid solution (battery acid with a specific gravity of 1,219).

The tube shall then be subjected to the burst test specified in 8.5.5.

8.5.18.3 Criteria

The burst pressure, p_b, shall be not less than 85 % of the minimum design burst pressure.

8.5.19 Vacuum test

8.5.19.1 General

This test is optional for Type 4 tubes only. When this test is carried out, one tube shall be subjected to a vacuum test prior to the environmental cycle test (see 8.5.7). When this test is not carried out, a warning shall be permanently marked on the tube label (see 10.2).

8.5.19.2 Procedure

The tube shall be subjected to a series of cycles from atmospheric pressure to a vacuum.

The contents (inert gas or air) shall be reduced from atmospheric pressure to a pressure of 0,2 bar absolute at ambient temperature. The vacuum shall be maintained at this level for at least 1 min.

The pressure in the tube shall be returned to atmospheric pressure. The total number of cycles shall be 50.

The parameters that shall be monitored and recorded are:

a) number of cycles achieving lower cyclic pressure;

b) minimum and maximum cyclic pressures;

c) cycle frequency;

d) results of the visual inspection.

8.5.19.3 Criteria

After cycling, the interior of the liner shall be inspected for damage. Any evidence of disbonding, folding or other damage shall be noted. If the tube then passes the environmental cycle test (see 8.5.7), it shall also be deemed to have passed the vacuum test.

8.5.20 High velocity impact (gunfire) test

8.5.20.1 General

This test is required for all Type 3 and Type 4 composite tubes. This test is required for Type 2 composite tubes that are to be used in military applications.

8.5.20.2 Procedure

One tube shall be filled to 2/3 of the test pressure, p_h, with air or nitrogen.

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 90° and such that the bullet would also exit through the tube side wall.

Tubes shall be impacted by a 7,62 mm (0,3 calibre) armour-piercing projectile with a nominal speed of 850 m/s (e.g. the 7,62 × 51 M993 AP NATO round).

The bullet shall be fired from a distance of not more than 45 m.

It is not necessary for the bullet to penetrate the tube side wall.

After the test, the tube shall be rendered unserviceable. Parameters to monitor and record are:

a) type of projectile;

b) initial pressure;

c) description of failure if applicable.

8.5.20.3 Criteria

The tube passes the test if either:

a) the bullet penetrates the tube and it does not rupture (it remains in one piece); or

b) the bullet does not penetrate the tube side wall.

8.5.21 Glass transition temperature test

The glass transition temperature of the matrix materials shall be tested in accordance with ASTM E135 or an equivalent standard. This test shall be repeated when matrix materials are changed from the matrix materials in the original design.

The matrix materials shall meet the minimum glass transition temperature specified by the tube manufacturer.

8.5.22 Resin shear strength test

Matrix materials shall be tested on a sample coupon representative of the composite overwrap in accordance with ISO 14130, ASTM D2344 or another equivalent document. This test shall be repeated when matrix materials are changed from the matrix materials in the original design.

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

8.6 Failure of type approval tests

In the event of failure to meet test requirements, an investigation into the cause of failure and re-testing shall be carried out in accordance with 9.6.

9 Inspection and testing at time of manufacture

9.1 Liners for Type 2 and Type 3 tubes

9.1.1 Metal tubing used to manufacture Type 2 and Type 3 liners shall be ultrasonically examined in accordance with Annex C.

Additionally, all steel liners used to manufacture Type 2 and Type 3 composite tubes shall be ultrasonically examined after completion of all heat treatment in accordance with Annex C.

9.1.2 Every liner shall be inspected for:

a) surface finish for defects by visual inspection;

b) dimensions: diameter and length, out of roundness and straightness;

c) neck folds: interior folding in the liner neck area shall be prohibited; smooth gathering of the material in the neck in which there are no sharp rooted folds shall be acceptable;

d) minimum wall thickness;

e) mass;

f) thread conformity.

9.1.3 If finished Type 2 or 3 tubes are subjected to proof test, then 100 % of liners shall be subjected to hardness test, if they are heat treated, after heat treatment in accordance with ISO 6506-1 or ISO 6508-1, and shall achieve the limits specified in 7.2.2.

If the finished tube is subjected to the volumetric expansion pressure test then 5 % of liners shall be subjected to the hardness test after heat treatment in accordance with ISO 6506-1 or ISO 6508-1, and shall achieve the limits specified in 7.2.2.

9.1.4 From every batch of load-sharing liners, one representative coupon taken from the supplied tubing subjected to the same heat treatment shall be tested to determine that the mechanical properties meet the minimum design requirements and according to the relevant standard for the liner material (see Clause 2).

9.1.5 A record of the tests carried out shall be kept by the tube manufacturer. Suitable forms of test certificate are shown in Annex B.

9.1.6 In the event of failure to meet test requirements, an investigation into the cause of failure and re-testing shall be carried out in accordance with 9.6.

9.2 Failure of load-sharing liner batch tests

9.2.1 If any of the test results are not satisfactory, and if the inspector is satisfied that this was due to an error carrying out the test, a re-test can be authorized using the same liner otherwise, at the discretion of the manufacturer, either:

a) the test in question shall be repeated on two specimens, one from the same liner or test ring as for the first test and another one from a liner or test ring from the same batch, and if both results are satisfactory the batch shall be accepted; or

b) where heat treatment has been shown to be inadequate, the batch of liners can be re-heat treated (if appropriate) and re-tested in accordance with 9.1.2 and 9.1.3, and, if the results are satisfactory, the batch shall be accepted; this re-treatment can be conducted once only.

9.2.2 Where heat treatment furnace records show artificial ageing has been inadequate, additional time at the ageing temperature shall be given.

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

9.3 Liners for Type 4 tubes

9.3.1 Each batch of non-load sharing liners shall be examined and dimensionally checked to ensure compliance with the design specifications. The following inspections shall be carried out in accordance with the manufacturer's quality assurance procedures:

a) visual inspection of external and internal surface finish;

b) dimensions: diameter and length;

c) thread conformity.

9.3.2 Each batch of metal bosses shall be tested to determine that the required properties specified in 7.2.2 have been achieved. The manufacturer's certification (mechanical properties, chemical analysis) is acceptable to demonstrate compliance.

9.3.3 Two representative coupons from every batch of non-metallic material shall be tested in accordance with ISO 527-1 and ISO 527-2 to determine that the required properties have been achieved.

Acceptance of non-metallic liners shall take into account:

a) the properties of the material (raw material as granulate, etc.) shall be within the tolerances set by the material manufacturer for melt flow index, density and either glass transition temperature or Vicat softening temperature;

b) the process parameters during liner manufacturing shall be within the tolerances agreed during type approval of the process;

c) the material properties of the liner shall be within the tolerances required by the design requirements laid down in 7.2.2.

Manufacturer's certification is acceptable to demonstrate compliance.

9.3.4 A record of the tests carried out shall be kept at the premises of the tube manufacturer. Suitable forms of test certificates are shown in Annex B.

9.4 Failure of non-load sharing liner batch tests

If any of the test results are not satisfactory and if the inspector is satisfied that this was due to an error carrying out the test, a re-test can be authorized using the same liner or material sample.

9.5 Overwrap materials

9.5.1 If the results of the verifications and tests are satisfactory that the design, manufacture, inspection and testing were carried out in accordance with this document, the inspector shall issue a certificate. An example form of certificate is shown in Annex B.

9.5.2 Supplier's certification of the material properties shall serve as verification of compliance. The strength of fibres shall be not less than specified in the documentation listed in 7.2.3.

9.5.3 If certification is not available, each batch of filament materials shall be subjected to an impregnated strand test in accordance with ISO 3341 for glass fibre, ASTM D7269 for aramid and ISO 10618 for carbon fibre, or appropriate equivalent standards. The strength of fibres shall be not less than specified in the documentation listed in 7.2.3.

9.5.4 Prototype matrix materials shall be tested on a sample coupon representative of the composite overwrap in accordance with ISO 14130 or an equivalent standard. These tests shall be repeated when matrix materials (i.e. resin, curing agent, accelerator) are changed to be different but are chemically equivalent to the original design.

9.6 Composite tube

9.6.1 If the results of the verifications and tests satisfactorily convey that the design, manufacture, inspection and testing were carried out in accordance with this document, the inspector shall issue a certificate. An example form of certificate is shown in Annex B.

9.6.2 Each batch of composite tubes shall be examined and checked to ensure conformance to the design standard. Inspections shall be carried out in accordance with the manufacturer's quality assurance procedures:

a) visual inspection of external and internal surface finish;

b) dimensions;

c) markings;

d) water capacity;

e) mass within the tolerance of the approved design;

f) cleanliness.

9.6.3 The internal and external surfaces of the finished tube shall be free from defects and residues from the manufacturing process (e.g. swarf, resin), which would adversely affect the safe working of the tubes. See ISO 11120 and ISO 7866 for guidance on possible defects in metallic liners.

9.6.4 Each completed tube shall be subjected to a hydraulic proof test (in accordance with 8.5.2) or a volumetric expansion test (in accordance with 8.5.3) at the design test pressure specified in 7.2.4. The elastic expansion and permanent expansion results shall be within the range specified in the design submission given in 7.2.4.

9.6.5 All tubes incorporating non-load sharing liners or bonded bosses shall be tested for leakage in accordance with 8.5.12.

Leak testing shall be conducted on the completed tube and shall be performed at two thirds of the test pressure, p_h.

9.6.6 One tube for every five batches shall be subjected to an ambient cycle test in accordance with 8.5.6.

9.6.7 One tube per batch shall be subjected to a burst test in accordance with 8.5.5.

9.7 Failure of batch tests

9.7.1 In the event of failure to meet test requirements during batch tests an investigation into the cause of failure and re-testing shall be carried out.

9.7.2 If there is evidence of a fault in carrying out a test, or an error of measurement, a second test shall be performed on the same tube, if possible. If this is not possible, then a second test shall be performed on a tube selected at random from the batch. If the results of this test are satisfactory, the first test shall be ignored.