INTERNATIONAL STANDARD

ISO 7866

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

Bouteilles à gaz — Bouteilles à gaz sans soudure en alliage d'aluminium destinées à être rechargées — Conception, construction et essais

Reference number
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Foreword

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

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

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

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 7866 was prepared by Technical Committee ISO/TC 58, *Gas cylinders*, Subcommittee SC 3, and by Technical Committee CEN/TC 23, *Transportable gas cylinders* in collaboration.

This second edition cancels and replaces the first edition (ISO 7866:1999), which has been technically revised.

The following significant technical changes have been carried out:

— a new subclause (11.7) has been added to address unacceptable manufacturing defects and unacceptable surface features at the time of manufacture and changes have been made to other subclauses to compliment the new subclause;

— terms and definitions and the symbols have been revised;

— terminology changes included: “stress” changed to “strength”;

— various editorial errors were corrected;

— equipment calibration requirements were added;

— defining "defect" as a feature caused by the manufacturing/manufacturer; and

— defining "imperfection" as damage or feature not caused by manufacturing/manufacturer.

Introduction

The purpose of this International Standard is to provide a specification for the design, manufacture, inspection and testing of a seamless aluminium alloy gas cylinder for worldwide usage. The objective is to balance design and economic efficiency against international acceptance and universal utility.

This International Standard aims to eliminate the concern about climate, duplicate inspections and restrictions currently existing because of lack of definitive International Standards. This International Standard should not be construed as reflecting on the suitability of the practice of any nation or region.

Following publication, this International Standard will be submitted for reference in the UN Recommendations on the Transport of Dangerous Goods – Model Regulations.

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

1 Scope

This International Standard specifies minimum requirements for the material, design, construction and workmanship, manufacturing processes and tests at time of manufacture of refillable seamless aluminium alloy gas cylinders of water capacities up to and including 150 litres for compressed, liquefied and dissolved gases for worldwide use (normally up to +65 °C).

2 Normative references

The following referenced documents are indispensable for the application 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 6506-1, *Metallic materials — Brinell hardness test — Part 1: Test method*

ISO 6508-1, *Metallic materials — Rockwell hardness test — Part 1: Test method (scales A, B, C, D, E, F, G, H, K, N, T)*

ISO 6892-1, *Metallic materials — Tensile testing — Part 1: Method of test at room temperature*

ISO 7438, *Metallic materials — Bend test*

ISO 7539-6:2011, *Corrosion of metals and alloys — Stress corrosion testing — Part 6: Preparation and use of pre-cracked specimens for tests under constant load or constant displacement*

ISO 10461, *Gas cylinders — Seamless aluminium-alloy gas cylinders — Periodic inspection and testing*

ISO 11117, *Gas cylinders — Valve protection caps and valve guards — Design, construction and tests*

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

ISO 13769, *Gas cylinders — Stamp marking*

3 Terms and definitions

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

3.1
artificial ageing
heat treatment process in which the solute phase is precipitated to give an increased yield strength and tensile strength

3.2
bar·litres
product of the test pressure (in bars) and the water capacity (in litres)

3.3
batch
quantity of gas cylinders, plus gas cylinders for destructive testing, of the same nominal diameter, wall thickness, length and design, made successively from the same cast of aluminium alloy and subjected to the same heat treatment on the same equipment for the same duration of time

NOTE See Table G.1 for batch size requirements.

3.4
design stress factor (variable)
F
ratio of equivalent wall stress at test pressure, p_h, to the guaranteed minimum yield strength, R_{eg}

3.5
IAA
registration record of international alloy designations and chemical composition limits for wrought aluminium and wrought aluminium alloys as published by the Aluminum Association[1)]

NOTE Such aluminium alloys are designated by the prefix "AA".

3.6
mass of a gas cylinder
combined mass of the gas cylinder and all permanently attached parts (e.g. foot ring, neck ring), but without the valve

NOTE Mass is expressed in kilograms.

3.7
quenching
controlled rapid cooling in a suitable medium to retain the solute phase in solid solution

3.8
solution heat treatment
thermal treatment which consists of heating products to a suitable temperature and holding them at that temperature long enough to allow constituents to enter into solid solution

3.9
stabilizing heat treatment
non-ageing heat treatment applied to 5 000-series aluminium alloys in order to minimize changes in mechanical properties and structure under service conditions

3.10
yield strength
value corresponding to the 0,2 % proof strength (0,2% non-proportional elongation), $R_{p0,2}$, for aluminium alloys

4 Symbols

a calculated minimum wall thickness, in millimetres, of the cylindrical shell (see Figure 1)

a' guaranteed minimum wall thickness, in millimetres, of the cylindrical shell

A percentage elongation after fracture

b guaranteed minimum thickness, in millimetres, at the centre of a convex base (see Figure 1)

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

d'	positive circular development of fracture
d''	negative circular development of fracture
D	nominal outside diameter, in millimetres, of the cylinder (see Figure 1 and Figure 2)
D_1	nominal outside diameter, in millimeters, of the cylinder neck (see Figure 2)”.
D_f	diameter, in millimetres, of the bend test former (see Figure 5)
E	modulus of elasticity
F	design stress factor (variable) (see 3.4)
H	outside height, in millimetres, of the domed part (convex head or base end) (see Figure 1)
L'	length of short branch of fracture, in millimeters
L''	length of long branch of fracture, in millimeters
L_o	original gauge length, in millimetres, as defined in ISO 6892-1 (see Figure 4)
n	ratio of the diameter of the bend test former to the actual thickness of the test specimen, t
p_b	actual burst pressure, in bars above atmospheric pressure
p_f	failure pressure, in bars
p_h	hydraulic test pressure, in bars above atmospheric pressure
p_u	upper cycling pressure, in bars
p_y	observed pressure when gas cylinder starts yielding during hydraulic bursting test, in bars above atmospheric pressure
r	inside knuckle radius, in millimetres (see Figure 1)
r_c	tip radius, in millimeters
r_i	inside crown radius, in millimetres (see Figure 1)
R	maximum stress value, in MPa
R_{ea}	actual value of the yield strength, in megapascals, as determined by the tensile test specified in 10.2 for the finished gas cylinder
R_{eg}	minimum guaranteed value of the yield strength (see 3.10), in megapascals, for the finished gas cylinder
R_{ma}	actual value of the tensile strength, in megapascals, as determined by the tensile test specified in 10.2 for the finished gas cylinder
R_{mg}	minimum guaranteed value of the tensile strength, in megapascals, for the finished gas cylinder
$R_{p0,2}$	0,2 % proof strength (0,2% non-proportional elongation), for aluminium alloys
S_o	original cross-sectional area, in square millimetres, of the tensile test specimen in accordance with ISO 6892-1
t	actual wall thickness, in millimetres, of the test specimen

t_m average cylinder wall thickness, in millimetres, in the position of testing during the flattening test

T titre of hydrogen peroxide in g per litre

u ratio of distance between knife edges at the end of test to the average cylinder wall thickness

w width, in millimetres, of the narrow, parallel-sided section of a tensile test specimen (see Figure 4)

z correction factor

5 Inspection and testing

NOTE Evaluation of conformity can be performed in accordance with the regulations recognized by the country(ies) where the gas cylinders are intended to be used.

To ensure that the gas cylinders conform to this International Standard, they shall be subjected to inspection and testing in accordance with Clauses 9, 10 and 11 by an inspection body, hereafter referred to as the “Inspection Body”, authorized to do so.

Equipment used for measurement, testing and examination during production shall be maintained and calibrated within a documented quality managment system.

6 Materials

6.1 General requirements

6.1.1 Aluminium alloys and their chemical composition limits shall be as specified in Table 1. Other aluminium alloys may be used to produce gas cylinders provided they satisfy all the requirements of this International Standard and are approved by the relevant authority for cylinder use.

6.1.2 The gas cylinder manufacturer shall identify the gas cylinders with the particular casts of the alloy from which they are made, and shall obtain and provide certificates of the analysis of the casts used. If check analysis is required, they shall be carried out either on test specimens taken from material in the form supplied by the producer of the aluminium alloy or from finished gas cylinders.

6.1.3 Some aluminium alloys are not compatible with certain gases and gas mixtures, e.g. corrosive gases (see ISO 11114-1). The manufacturer shall use materials compatible with the intended gas service when the purchaser indicates the intended gas.

Table 1 — Chemical composition of materials

Group	Type of alloy (IAA registered AA designation)		**Chemical composition** (% by mass)											**Others**		Al
			Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Zr	Pb	Each	Total	
1	6351A	min.	0,7	—	—	0,40	0,40	—	—	—	—	—	—	—	—	Remainder
		max.	1,3	0,50	0,10	0,8	0,8	—	—	0,20	0,20	—	0,003 0	0,05	0,15	
	6082A	min.	0,7	—	—	0,40	0,60	—	—	—	—	—	—	—	—	Remainder
		max.	1,3	0,50	0,10	1,0	1,2	0,25	—	0,20	0,10	—	0,003 0	0,05	0,15	
	6061A	min.	0,40	—	0,15	—	0,8	0,04	—	—	—	—	—	—	—	Remainder
		max.	0,8	0,7	0,40	0,15	1,2	0,35	—	0,25	0,15	—	0,003 0	0,05	0,15	
2	5283A	min.	—	—	—	0,50	4,5	—	—	—	—	—	—	—	—	Remainder
		max.	0,30	0,30	0,03	1,0	5,1	0,05	0,03	0,10	0,03	0,05	0,003 0	0,05	0,15	
3	7060	min.	—	—	1,8	—	1,3	0,15	—	6,1	—	—	—	—	—	Remainder
		max.	0,15	0,20	2,6	0,20	2,1	0,25	—	7,5	0,05	0,05	0,003 0	0,05	0,15	
	7032	min.	—	—	1,7	—	1,5	0,15	—	5,5	—	—	—	—	—	Remainder
		max.	0,10	0,12	2,3	0,05	2,5	0,25	0,05	6,5	0,1	0,05	0,003 0	0,05	0,15	
4	2001	min.	—	—	5,2	0,15	0,20	—	—	—	—	—	—	—	—	Remainder
		max.	0,20	0,20	6,0	0,50	0,45	0,10	0,05	0,10	0,20	0,05	0,003 0	0,05	0,15	

The bismuth content shall not exceed 0,0030 % (by mass).

NOTE The above materials are used extensively throughout the world in preference to the alloy compositions quoted in ISO 209. They are included in this International Standard quoting the IAA registered designations, but making reference to ISO 209 where it is considered applicable.

6.2 Thermal treatments

6.2.1 Heat-treatable alloys (see Table 1, groups 1, 3 and 4)

The manufacturer shall specify, in the type approval documentation, the solution heat treatment and artificial-ageing temperatures and the minimum times for which the gas cylinders have been held at those temperatures. The medium used for quenching after solution heat treatment shall be identified.

6.2.2 Non-heat-treatable alloys (see Table 1, group 2)

The manufacturer shall specify, in the type approval documentation, the type of metal-forming operation carried out (extrusion, drawing, ironing, head forming, etc.).

Unless the alloy is subjected to a temperature in excess of 400 °C during the forming process, a stabilizing heat treatment shall be carried out at a temperature above 220 °C, and the temperature and time at that temperature shall be identified by the manufacturer.

6.2.3 Control of specified heat treatment

During the heat treatment, the manufacturer shall comply with the following tolerances:

a) temperatures:

— solution temperature ±10 °C,

— artificial ageing temperature ±5 °C,

— stabilizing temperature ±10 °C;

b) time gas cylinders actually spend at this temperature during treatment:

— solution treatment ±30 %,

— ageing treatment ±20 %,

— stabilizing treatment ±10 %.

6.3 Test requirements

The material of the finished gas cylinders shall conform to Clauses 9, 10 and 11.

6.4 Failure to meet test requirements

6.4.1 In the event of failure to meet test requirements, retesting or reheat treatment and retesting shall be carried out as follows:

a) If there is evidence of a fault in carrying out a test, or an error of measurement, a second test shall be performed, on the same gas cylinder if possible. If the result of this test is satisfactory, the first test shall be ignored.

b) If the test has been carried out in a satisfactory manner and the failure is in a test representing the prototype or batch gas cylinders, the procedure detailed in either 6.4.2 or 6.4.3 shall be followed.

c) If the test has been carried out in a satisfactory manner and the failure is in a test applied to every gas cylinder, then only those gas cylinders which failed the test require retesting or reheat treatment and retesting, provided the cause of the failure is well identified. If the failure is due to the heat treatment applied, the failed gas cylinders shall be subjected to the procedure in 6.4.3. If the failure is due to a cause other than the heat treatment applied, all defective gas cylinders shall be rejected.

6.4.2 Two further gas cylinders selected at random from the same batch shall be subjected to the tests specified in 10.1.3 a) and 10.1.3 b). If both gas cylinders meet the specified requirements, the batch shall be accepted. Should either gas cylinder fail to meet the specified requirements, the batch shall

a) be rejected,

or

b) be treated in accordance with 6.4.3.

6.4.3 The batch of gas cylinders shall be reheat-treated and two further gas cylinders shall be tested in accordance with 10.1.3 a) and 10.1.3 b). If both gas cylinders meet the specified requirements, the batch shall be accepted. Should either gas cylinder fail to meet the specified requirements, the batch shall be rejected.

6.4.4 For heat-treatable alloys, where it can be established that the heat treatment was at fault for failure of a test, the batch of gas cylinders may additionally (more than once) be re-solution heat-treated and/or aged. However, the batch may only be submitted to the Inspection Body one more time for testing after the initial submission. If the batch presented to the Inspection Body for the second test or tests fails one or more tests, the batch shall be condemned.

7 Design

7.1 General requirements

7.1.1 The calculation of the wall thickness of the pressure-containing parts shall be related to the yield strength, R_{eg}, of the material.

7.1.2 For calculation purposes, the value of the yield strength, R_{eg}, is limited to a maximum of $0{,}90R_{mg}$ for seamless aluminium alloy gas cylinders.

7.1.3 The internal pressure upon which the calculation of wall thickness is based shall be the hydraulic test pressure, p_h.

7.1.4 Wherever any exposure to heat is necessary (e.g. for gas cylinders for dissolved acetylene, where the process by which the porous material is manufactured can modify the characteristics of the aluminium alloy used; see Annex H), this shall be considered when designing the shell.

7.2 Calculation of cylindrical shell thickness

The guaranteed minimum thickness of the cylindrical shell, a', shall not be less than the thickness calculated using relationships (1) and (2), and additionally condition (3) shall be satisfied:

$$a = \frac{D}{2}\left(1 - \sqrt{\frac{10FR_{eg} - \sqrt{3}p_h}{10FR_{eg}}}\right) \tag{1}$$

where

the value of F is the lesser of $\dfrac{0{,}65}{R_{eg}/R_{mg}}$ and 0,85;

R_{eg}/R_{mg} shall not exceed 0,90.

The wall thickness shall also satisfy the relationship:

$$a \geq \frac{D}{100} + 1\ \text{mm} \tag{2}$$

with an absolute minimum of 1,5 mm.

The burst ratio shall be satisfied by test. The following condition shall be met:

$$p_b/p_h \geq 1{,}6 \tag{3}$$

When choosing the minimum guaranteed value of the thickness of the cylindrical shell, a', the manufacturer shall ensure that the thickness is sufficient to satisfy both the calculations and the required verification testing.

NOTE It is generally assumed that $p_h = 1{,}5 \times$ the service pressure for compressed gases for gas cylinders designed and manufactured to this International Standard.

7.3 Design of ends (heads and bases)

7.3.1 The thickness and shape of the base and head of the gas cylinders shall be such as to meet the requirements of the tests specified in 10.4 (hydraulic burst test) and 9.2.3 (pressure-cycling test).

To achieve satisfactory stress distribution, the gas cylinder wall thickness shall increase progressively in the transition zone between the cylindrical shell and the ends, particularly the base. Examples of typical shapes of convex heads and base ends are shown in Figure 1.

7.3.2 The thickness at any part of a convex end shall be not less than the minimum wall thickness of the cylindrical part.

7.3.3 The inside crown radius, r_i, shall be not greater than 1,2 × the inside diameter of the shell, and the knuckle radius, r, shall be not less than 10 % of the inside diameter of the shell.

7.3.4 Where the conditions of 7.3.3 are not fulfilled, the gas cylinder manufacturer shall prove by the prototype tests as required in 9.2 that the design is satisfactory.

7.4 Neck design

7.4.1 The external diameter and thickness of the formed neck end of the gas cylinder shall be adequate for the stresses resulting from the fitting of the valve to the gas cylinder. The stresses can vary according to the thread diameter, its form and the sealant used in fitting the valve. The requirements specified in ISO 13341 (or as recommended by the manufacturer where that International Standard does not apply) shall be applied, since permanent damage to the gas cylinder could otherwise result.

7.4.2 In establishing the minimum thickness, consideration shall be given to obtaining a thickness of the wall in the gas cylinder neck which will prevent permanent expansion of the neck during the initial and subsequent fittings of the valve into the gas cylinder.

In specific cases (e.g. very thin walled cylinders), where the stresses resulting from the initial and subsequent fittings of the valve to the gas cylinder cannot be supported by the neck itself, the neck may be designed to require reinforcement, such as a neck ring or shrunk-on collar, provided the reinforcement material and dimensions are clearly specified by the manufacturer and this configuration is part of the type approval procedure.

7.4.3 Gas cylinders may be designed with one or two openings but both shall be along the central gas cylinder axis.

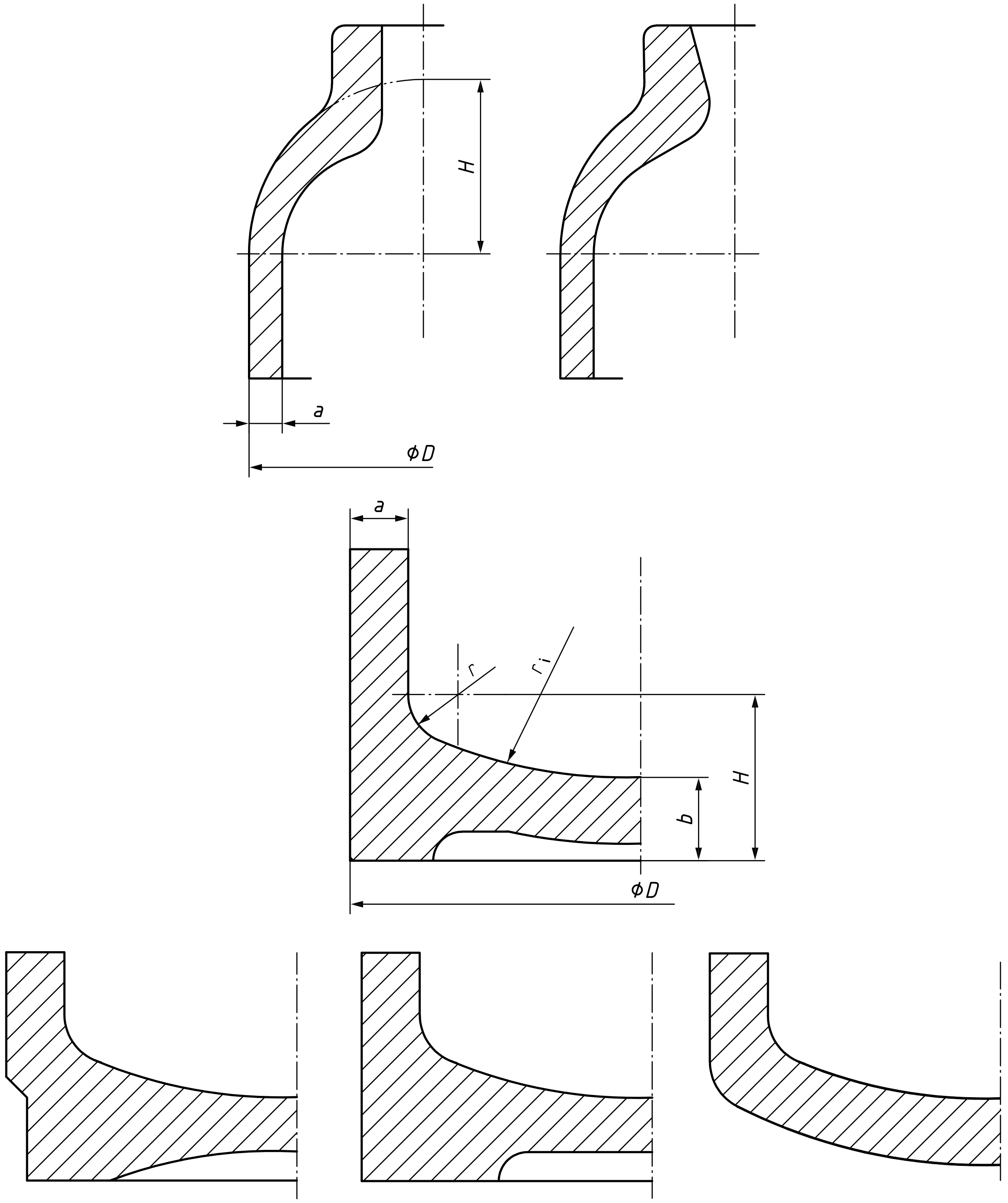


Figure 1 — Typical ends

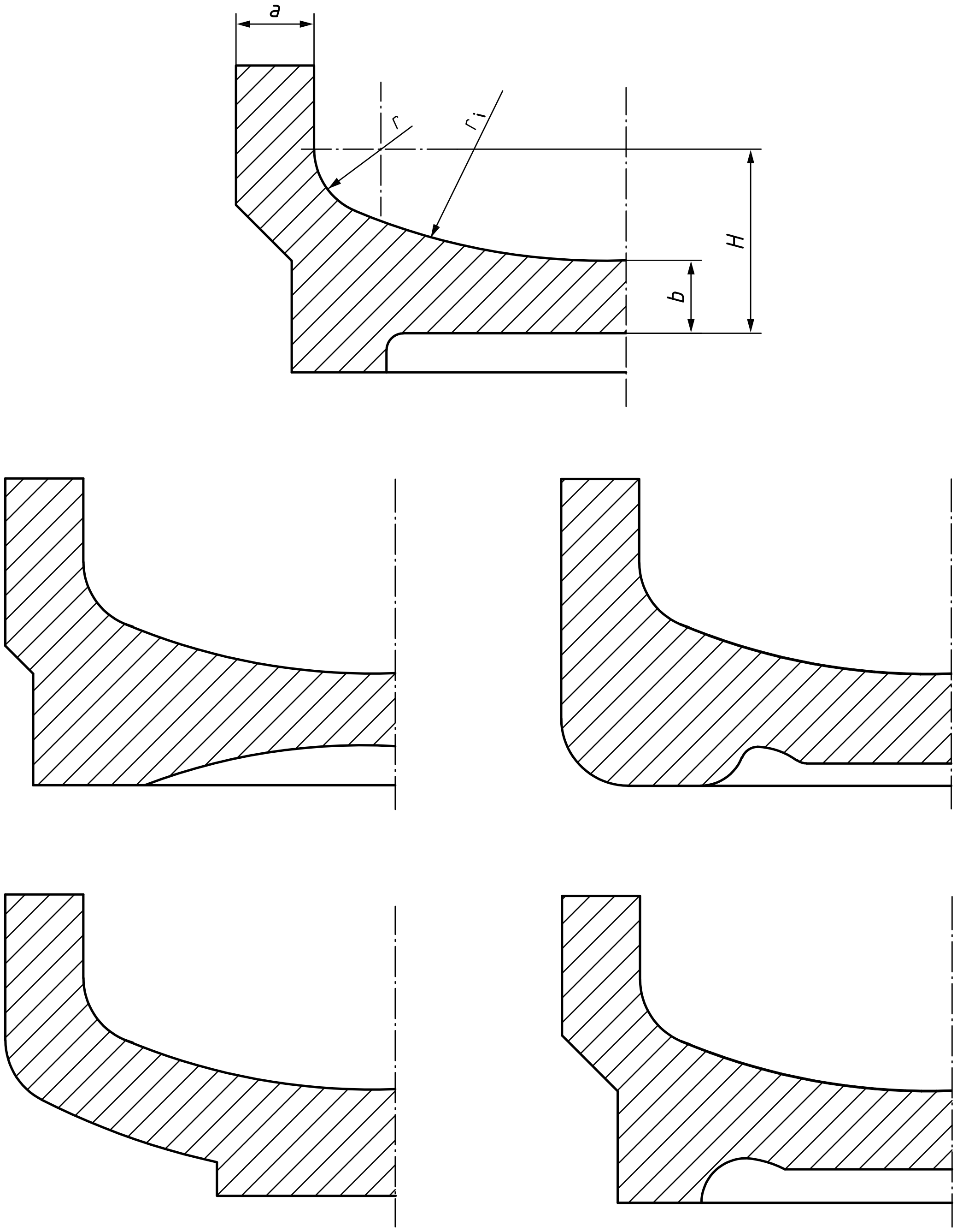


Figure 1 — Typical ends (*continued*)

7.5 Foot rings

When a foot ring is provided, it shall be sufficiently strong and made of material compatible with that of the gas cylinder. The shape should preferably be cylindrical and shall give the gas cylinder sufficient stability. The foot ring shall be secured to the gas cylinder by a method other than welding, brazing or soldering. To prevent ingress of water, any gaps which could form water traps shall be sealed by a method other than welding, brazing or soldering.

7.6 Neck rings

When a neck ring is provided, it shall be sufficiently strong and made of material compatible with that of the gas cylinder, and shall be securely attached by a method other than welding, brazing or soldering.

The manufacturer shall ensure that the axial load necessary to remove the neck ring is greater than 10 × the mass of the empty gas cylinder, but not less than 1 000 N, and that the minimum torque necessary to rotate the neck ring is 100 N·m.

Where the gas cylinder manufacturer fits valve protection, it shall be in accordance with the requirements specified in ISO 11117.

7.7 Design drawing

A fully dimensioned drawing, including tolerances, shall be prepared which includes the specification of the material and makes reference to this International Standard.

7.8 High-strength and/or low-elongation gas cylinder designs

Requirements for these designs are given in Annex E.

8 Construction and workmanship

8.1 General

The gas cylinder shall be produced by

a) cold or hot extrusion from cast or extruded or rolled billet,

b) cold or hot extrusion from cast or extruded or rolled billet, followed by cold drawing,

c) cupping, flow forming, spinning and cold drawing sheet or plate,

d) open necking at both ends of an extruded or cold-drawn tube (see Figure 2), and

e) non-welding techniques.

Manufacturing defects shall not be corrected by plugging.

8.2 End forming

The neck shall be formed by an appropriate method, e.g. forging, swaging or spinning. Where heat has to be applied to form the gas cylinder's neck/shoulder, it shall be ensured that an appropriately controlled heat distribution is achieved prior to the forming operation, e.g. by means of induction heating. This approach shall be used irrespective of the method employed for the manufacture of the shell.

The end-forming operation chosen shall result in a visibly smooth surface, especially in the neck/shoulder areas, which has no feature or defect [e.g. unacceptable folds (see 11.5) or cracks] which will adversely affect the performance or integrity of the gas cylinder.

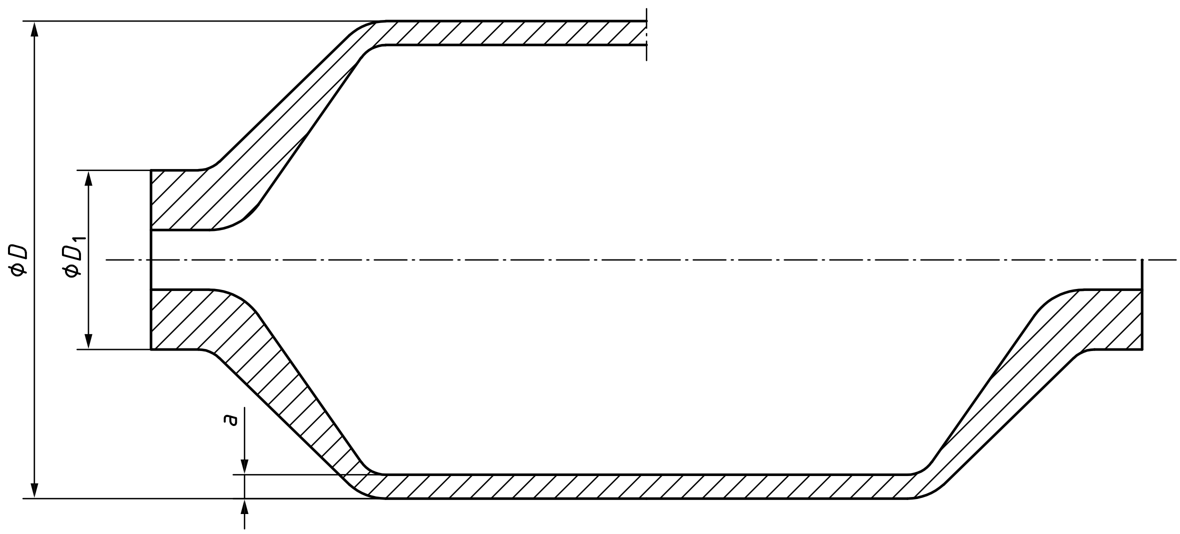


Figure 2 — Necked ends of tube

8.3 Wall thickness

Each gas cylinder shall be examined, at the time of production, for thickness. The wall thickness at any point shall be not less than the minimum thickness specified.

8.4 Surface imperfections and defects

Each gas cylinder shall be examined, at the time of production, for internal and external surface imperfections and defects.

The internal and external surfaces of the finished gas cylinder shall be free from defects that would adversely affect the safe working of the gas cylinder.

Such defects shall be removed by local dressing (where permitted) or the cylinder shall be condemned.

The wall thickness of any dressed areas shall not be less than the minimum thickness specified in the design.

Imperfections are subject to the requirements of 11.7.

8.5 Neck threads

The neck threads shall conform to the design specification to permit the use of a corresponding valve, thus minimizing neck stresses following the valve-fitting operation.

Neck threads shall be checked using gauges corresponding to the agreed neck thread, or by an alternative method agreed between the parties, e.g. where the internal neck thread is specified to be in accordance with ISO 11363-1 the corresponding gauges are specified in ISO 11363-2.

8.6 Out-of-roundness

The out-of-roundness of the cylindrical shell, i.e. the difference between the maximum and minimum outside diameters in the same cross-section, shall not exceed 2 % of the mean of these diameters.

8.7 Exposure to heat

Any exposure to heat after the heat treatment or stabilization treatment shall not modify the characteristics of the aluminium alloy used to the extent that the mechanical properties fall below the minimum guaranteed values. When exposure to heat is necessary (see 7.1.4), extensive trials shall be performed to verify that the minimum design criteria are always met.

8.8 Straightness

The maximum deviation of the cylindrical part of the shell from a straight line shall not exceed 3 mm per metre length.

8.9 Mean diameter

The mean external diameter shall not deviate from the nominal design diameter by more than ±1 % or ±1 mm, whichever is the larger.

9 Type approval procedure

9.1 General requirements

A technical specification for each new design of gas cylinder [or gas cylinder family in the case of item f) below], including a design drawing, design calculations, alloy details and details of heat treatment, shall be submitted by the manufacturer to the Inspection Body. The type approval tests detailed in 9.2 shall be carried out on each new design under the supervision of the Inspection Body.

A gas cylinder shall be considered to be of a new design compared with an existing approved design when

a) it is manufactured in a different factory; or

b) it is manufactured by a different process (see 8.1) [this includes the case when major process changes (e.g. a change in the neck-forming method) are made during the production period]; or

c) it is manufactured from an alloy of different composition limits from that used in the original prototype tests; or

d) it is given a different heat treatment that is outside the temperature and time ranges specified in 6.2.3; or

e) the base profile and the base thickness have changed relative to the gas cylinder diameter and calculated minimum wall thickness; or

f) the overall length of the gas cylinder has increased by more than 50 % (gas cylinders with a length/diameter ratio less than 3 shall not be used as reference gas cylinders for any new design with this ratio greater than 3); or

g) the nominal outside diameter has changed; or

h) the design wall thickness has changed; or

i) the hydraulic test pressure has been increased (where a gas cylinder is to be used for lower-pressure duty than that for which design approval has been given, it shall not be deemed to be a new design); or

j) the guaranteed minimum yield strength, R_{eg}, and/or the guaranteed minimum tensile strength, R_{mg}, have changed.

9.2 Prototype tests

9.2.1 General

A minimum of 50 gas cylinders, which are guaranteed by the manufacturer to be representative of the new design, heat treated to no more than the minimum times +10 % required in 6.2, shall be made available for prototype testing. If the gas cylinders are likely to experience exposure to heat in further processing (e.g. curing of porous material for acetylene service or heating for powder painting) (see 8.7), testing shall be carried out on representative gas cylinders. However, if the total number of gas cylinders required is less than 50, enough gas cylinders shall be made to complete the prototype tests required, in addition to the production quantity, but in this case the approval validity is limited to this particular production batch.

9.2.2 Inspection

In the course of the type approval process, the Inspection Body shall select the necessary gas cylinders for testing and then proceed as follows:

a) The Inspection Body shall verify that

- the materials conform to Clause 6;
- the design conforms to Clause 7;
- the thicknesses of the walls and ends on two of the gas cylinders taken for testing conform to 7.2, 7.3 and 7.4, the measurements being taken on three transverse sections of the cylindrical part and over the whole of a longitudinal section of the base and the head;
- the requirements of 7.5, 7.6 and 8.2 to 8.9 inclusive are met for all gas cylinders selected by the Inspection Body;
- the material meets the requirements of the intercrystalline and stress corrosion tests specified in Annex A [it is not necessary to carry out these tests when only condition 9.1 e) applies and/or when the nominal outside diameter has changed by less than 20 %];
- the sustained-load cracking test has been completed satisfactorily in accordance with Annex B.

  NOTE This is a “material” qualification test (see Clause B.2) and not a prototype test.

b) The Inspection Body shall then supervise the following tests on the gas cylinders selected:

- the tests specified in 10.1.3 a) (mechanical testing), but on two gas cylinders, the test specimens being identifiable with the batch;
- the tests specified in 10.1.3 b) (hydraulic burst test), but on two gas cylinders, the gas cylinders bearing representative markings;
- the tests specified in 9.2.3 (pressure-cycling test) on three gas cylinders, the gas cylinders bearing representative markings.

9.2.3 Pressure-cycling test

This test shall be carried out with a non-corrosive liquid, subjecting the gas cylinders to successive reversals at an upper cyclic pressure which is equal to the hydraulic test pressure, p_h. The gas cylinders shall withstand 12 000 cycles without failure.

For gas cylinders with a hydraulic test pressure, p_h, $>$ 450 bar, the upper cyclic pressure may be reduced to two-thirds of the test pressure. In this case, the gas cylinders shall withstand 80 000 cycles without failure.

The value of the lower cyclic pressure shall not exceed 10 % of the upper cyclic pressure, but with an absolute maximum of 30 bar.

The gas cylinder shall actually experience the maximum and minimum cyclic pressures during the test.

The frequency of reversals of pressure shall not exceed 0,25 Hz (15 cycles/min). The temperature measured on the outside surface of the gas cylinder shall not exceed 50 °C during the test.

After the test, the gas cylinder bases shall be sectioned in order to measure the thickness and to ensure that this thickness is sufficiently close, within the usual production tolerances, to the minimum thickness prescribed in the design. In no case shall the actual base thickness exceed that specified in the drawing by more than 15 %.

The test shall be considered satisfactory if the gas cylinder attains the required number of cycles without developing a leak.

9.2.4 Test requirements for high-strength and/or low-elongation gas cylinder designs

High-strength and/or low-elongation gas cylinder designs shall be subject to the requirements of Annex E.

9.3 Type approval certificate

If the results of the prototype tests in accordance with 9.2 are satisfactory, the Inspection Body shall issue (if authorized by the regulatory authority), or recommend that the regulatory authority issue, a type approval certificate, a typical example of which is given in Annex C.

10 Batch tests

10.1 General requirements

10.1.1 All tests for checking the quality of the gas cylinder shall be carried out on material from finished gas cylinders. Gas cylinders for mechanical and burst testing need not have been pressure-tested.

For the purpose of batch testing, the manufacturer shall provide the Inspection Body with

— the type approval certificate,

— certificates stating the cast analyses of the alloy supplied for the construction of the gas cylinders,

— a means of identifying the cast of the material from which each gas cylinder was made,

— a statement of the manufacturing processes utilized as specified in 8.1 and 8.2 and the relevant documentation relating to the heat and mechanical treatment,

— a list of the gas cylinders, stating serial numbers and stamp markings, as required,

— confirmation that threads conform to the approved manufacturer's drawing [the gauges to be used shall be specified (e.g. using ISO 11363-2)], and

— verification that the water capacity conforms to the design drawing.

10.1.2 During batch testing, the Inspection Body shall select the gas cylinders necessary for testing and then proceed as follows:

— The Inspection Body shall ascertain that the type approval certificate has been obtained and that the gas cylinders conform to it.

— The Inspection Body shall then check that the markings are in accordance with the design specification.

— The Inspection Body shall also check whether the requirements set out in Clauses 6, 7 and 8 have been met and, in particular, check by an external and, if physically possible, internal visual inspection of the gas cylinders whether their construction and the checks carried out by the manufacturer in accordance with 7.5, 7.6, 8.2 to 8.6, 8.8 and 8.9 are satisfactory. This visual examination shall cover at least 10 % of the gas cylinders submitted. Should an internal unaided visual examination be physically impossible, an alternative inspection method shall be agreed between the manufacturer and the Inspection Body. At least 10 % of the batch shall be checked by this method.

  However, if a gas cylinder not meeting the above requirements is found, then all of the gas cylinders shall be inspected.

— The Inspection Body shall witness the tests and verify that the results of the tests specified in 10.1.3 a) (mechanical testing) and 10.1.3 b) (hydraulic burst testing) are satisfactory. Where alternative tests are permitted, the purchaser and manufacturer shall agree which tests are to be carried out.

— The Inspection Body shall check whether the information supplied by the manufacturer referred to in 10.1.1 is correct (random checks shall be carried out);

— Finally, the Inspection Body shall assess the results of the hardness testing specified in 11.3.

10.1.3 The following tests shall be carried out on each batch of gas cylinders:

a) On one gas cylinder:

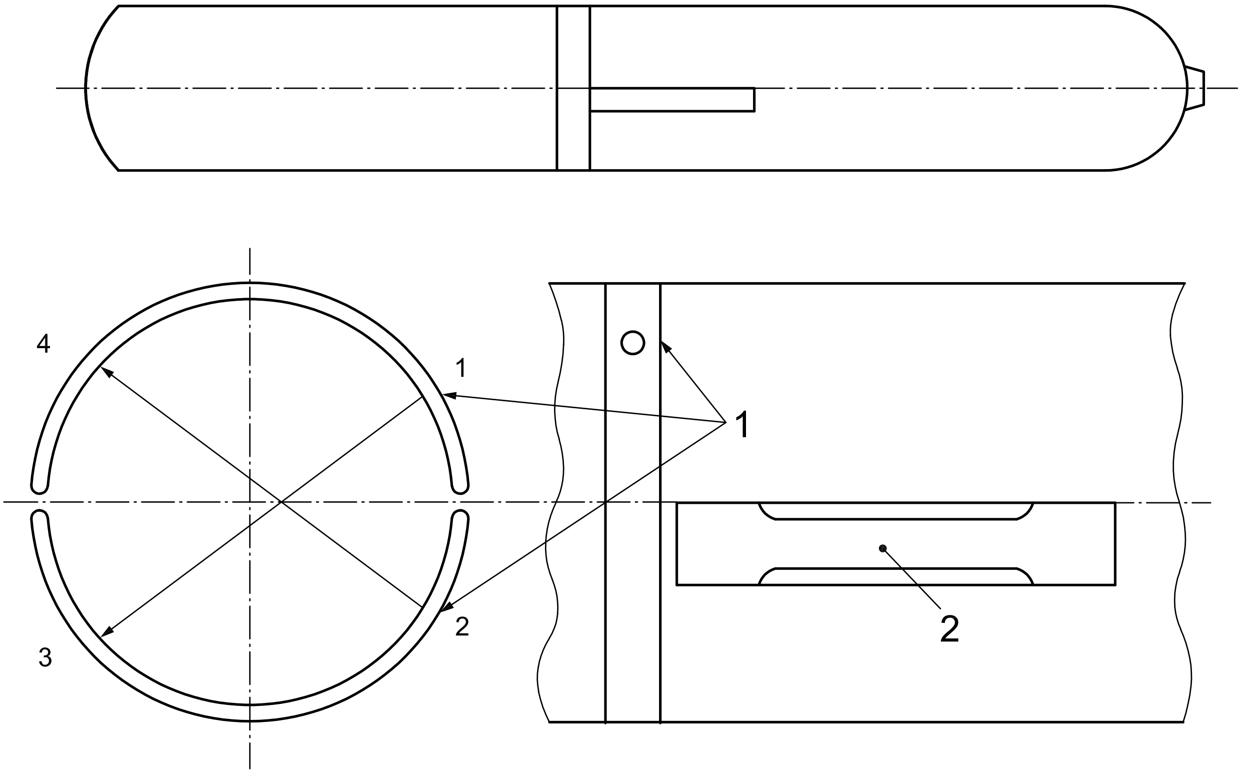
   1) one tensile test in the longitudinal direction (see 10.2);

   2) two bend tests in a circumferential direction (see 10.3.1) or a flattening test (see 10.3.2).

The location of the test specimens shall be in accordance with Figure 3.

b) On a second gas cylinder:

   1) one hydraulic burst test (see 10.4).



Key

1 bend test specimens

2 tensile test specimen

Figure 3 — Location of test specimens

10.2 Tensile test

10.2.1 The tensile test shall be carried out in accordance with ISO 6892-1 on a test specimen which is shaped in accordance with Figure 4 and with a gauge length given by $L_o = 5{,}65\sqrt{S_o}$.

The two faces of the test specimen representing the inside and the outside surfaces of the gas cylinder shall not be machined.

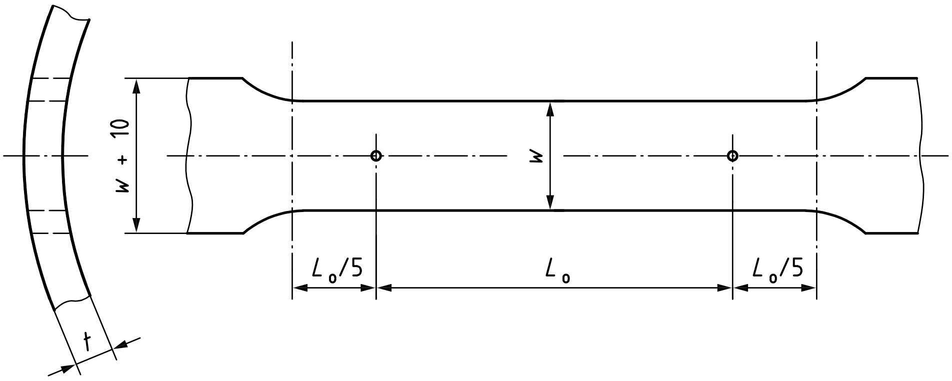
10.2.2 With regard to the heat-treatable alloys referred to in Table 1, the percentage elongation after fracture, A, shall be not less than 12 %, except for AA 2001 which is covered in Annex E.

With regard to the non-heat-treatable alloys referred to in Table 1, the elongation after fracture shall not be less than 12 % when the test is carried out on a single test specimen taken from the gas cylinder wall. The tensile test may also be carried out on four test specimens distributed uniformly throughout the gas cylinder wall. The results shall be as follows:

— no individual value may be less than 11,0 %;

— the average of the results from all the test specimens shall be at least 12,0 %.

Dimensions in millimetres



Test specimen dimensions when $t \geq 3$ mm:

$w \leq 4t$

$w < D/8$

Figure 4 — Tensile test specimen

10.3 Bend test and flattening test

10.3.1 Bend test

10.3.1.1 The bend test shall be carried out in accordance with ISO 7438 on two test specimens obtained by cutting either one or two rings of width 25 mm or $3t$, whichever is the greater, into four equal parts. The two test specimens shall be taken from the parts that were 180° apart. Each test specimen shall be of sufficient length to permit the bend test to be carried out correctly. Only the edges of each strip may be machined.

10.3.1.2 The test specimen shall not crack when bent inwards around the former until the inside surfaces are not further apart than the diameter of the former (see Figure 5).

10.3.1.3 The diameter of the former, D_f, shall be established, using the value of n given in Table 2 for the relevant actual tensile strength (R_{ma}) range, from the formula:

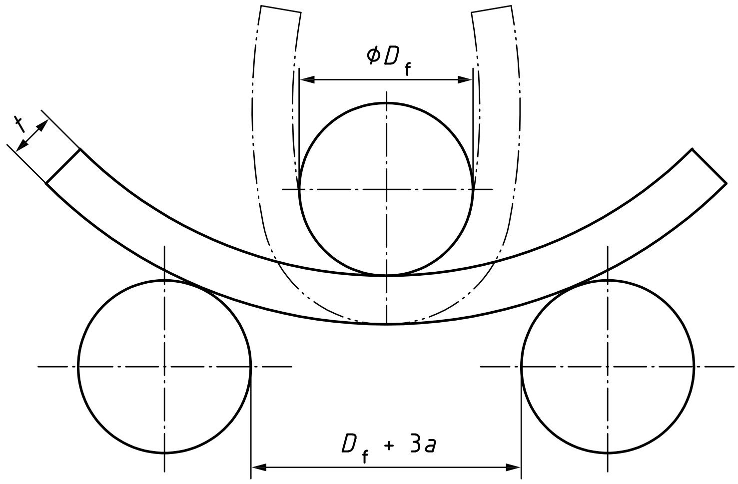
$$D_f = n \times t$$

where t is test specimen thickness

Table 2 — Bend test and flattening-test requirements

Actual tensile strength, R_{ma} MPa	**Value of n for bend test and flattening test** (see 10.3.1.3 and 10.3.2.2)	**Value of u for flattening test**[a]
$R_{ma} \leq 325$	6	10
$325 < R_{ma} \leq 440$	7	12
$R_{ma} > 440$	8	15

[a] Distance between knife edges at end of test $= u \times t_m$, where t_m is the average gas cylinder wall thickness at the position of test.



a calculated minimum thickness

Figure 5 — Illustration of bend test

10.3.2 Flattening test

10.3.2.1 The flattening test shall be performed on one gas cylinder selected from each batch after heat treatment.

10.3.2.2 The test gas cylinder shall be flattened between wedge-shaped knife edges with a 60° included angle. The maximum radius of the knife edges shall be established, using the value of n given in Table 2 for the relevant actual tensile strength (R_{ma}) range, from the formula:

Maximum radius $= n \times t_m$

where t_m is the average gas cylinder wall thickness at the position of test.

The length of the knife edges shall not be less than the width of the flattened gas cylinder. The longitudinal axis of the gas cylinder shall be at approximately 90° to the knife edges.

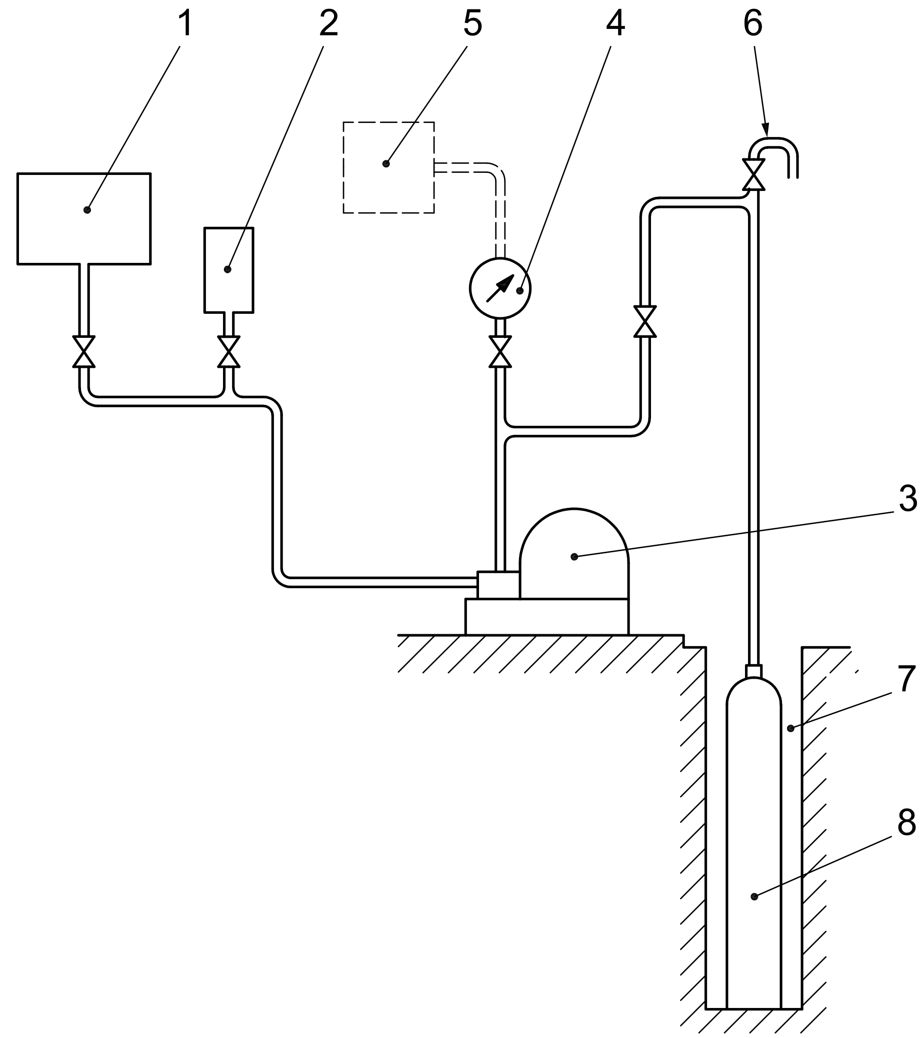
10.3.2.3 The test gas cylinder shall be flattened until the distance between the knife edges is in accordance with Table 2. The flattened gas cylinder shall remain visually uncracked.

10.4 Hydraulic burst test

10.4.1 Test installation

The test equipment shall be capable of operation in accordance with the test conditions specified in 10.4.2 and of producing accurately the information required by 10.4.3.

A typical hydraulic burst test installation is illustrated in Figure 6.



Key

1 test fluid reservoir

2 tank for measurement of test fluid (the feed tank may also be used as a measuring tank)

3 pump

4 pressure gauge

5 pressure/volumetric expansion curve recorder

6 vent or air release valve

7 test well

8 gas cylinder

Figure 6 — Typical hydraulic burst test installation

10.4.2 Test conditions

Because the gas cylinder and test equipment are being filled with water, care shall be taken to ensure that no air is trapped in the circuit. Do this by operating the hydraulic pump until water is discharged from the vent or air-release valve.

During the test, pressurization shall be carried out in two successive stages:

a) In the first stage, the pressure shall be increased at a rate of not more than 5 bar/s up to a pressure value corresponding to the initiation of plastic deformation.

b) In the second stage, the pump discharge rate shall be maintained at as constant a level as is possible until the gas cylinder bursts.

10.4.3 Interpretation of test

10.4.3.1 The interpretation of the burst test shall involve

a) examination of a pressure/time curve or a curve of pressure vs volume of water used, in order to permit determination of the pressure at which plastic deformation of the gas cylinder commences, together with the burst pressure and volumetric expansion of the gas cylinder during the test, and

b) examination of the burst tear and of the shape of its edges.

10.4.3.2 For the results of a burst test to be considered satisfactory, the following requirements shall be met:

a) The observed yield pressure, p_y, shall be equal to or greater than $1/F \times$ the test pressure, i.e.

$$p_y \geq \frac{1}{F} \times p_h$$

b) The actual burst pressure, p_b, shall be greater than or equal to 1,6 × the test pressure, i.e.

$$p_b \geq 1{,}6 p_h$$

10.4.3.3 The gas cylinder shall remain in one piece and shall not fragment.

10.4.3.4 The main tear shall not be of a brittle type, i.e. the edges of the fracture shall not be radial but shall be sloping in relation to a diametral plane. The tear shall not reveal a significant defect in the metal.

10.4.3.5 The fracture shall be considered acceptable only if it conforms to one of the following descriptions:

a) For gas cylinders of actual wall thickness 13 mm or less:

— the greater part of the fracture shall be unmistakably longitudinal except for gas cylinders where the ratio of length to outside diameter is less than 3:1;

— at each end of the fracture, no more than two branches (see L' and L'' in Figure 7) shall be allowed, and only if the shorter branch, which may be at either end, is less than 20 mm long;

— the fracture shall not extend more than 90° around the circumference on either side of its main part (see d' and d'' in Figure 7);

— the fracture shall not extend into those parts of the gas cylinder of thickness more than 1,5 × the maximum thickness measured halfway up the gas cylinder (for gas cylinders with convex bases, the fracture shall not reach the centre of the gas cylinder base).

b) For gas cylinders of actual wall thickness over 13 mm, the greater part of the fracture shall be longitudinal.

10.5 Test requirements for high-strength and/or low-elongation gas cylinder designs

High-strength and/or low-elongation gas cylinder designs shall be subject to the requirements of Annex E.

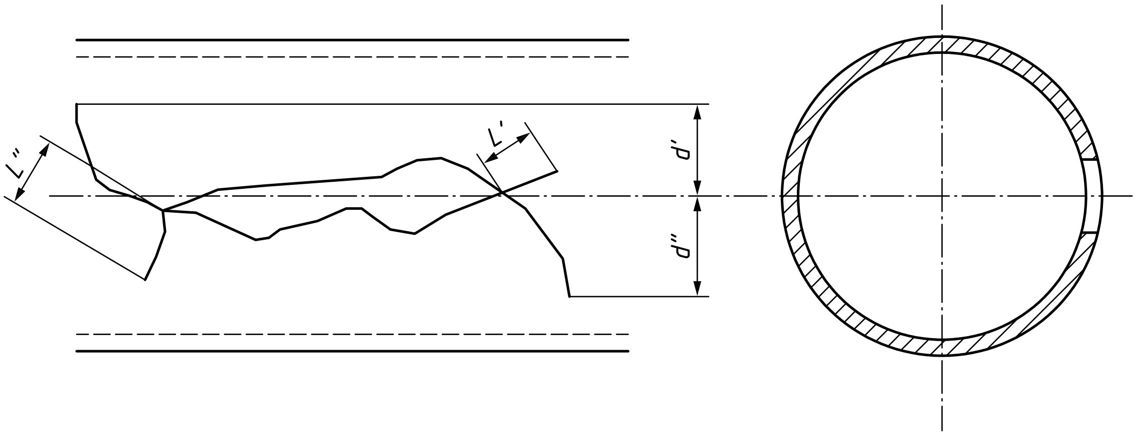


Figure 7 — Illustration of circumferential development of fracture

11 Gas cylinder tests and examinations

11.1 General

At the time of production, the examinations required in 8.3 and 8.4 shall be performed on each cylinder.

Following final heat treatment (see 6.2), all gas cylinders, except those selected for testing under Clause 10, shall be subjected to the following tests:

— Either a hydraulic proof pressure test in accordance with 11.2.1 or a hydraulic volumetric-expansion test in accordance with 11.2.2. The requirements to be met are given in 11.2.1 and 11.2.2, respectively. Additional guidance on these test methods and details of equipment calibration and maintenance can be found in ISO 10461. The purchaser and manufacturer shall agree which of these alternatives shall be carried out.

— A hardness test in accordance with 11.3.

— A leak test in accordance with 11.4.

— An examination for neck folds in accordance with 11.5.

11.2 Hydraulic test

11.2.1 Proof pressure test

The water pressure in the gas cylinder shall be increased at a controlled rate until the test pressure, p_h, is reached.

The gas cylinder shall remain under pressure p_h for at least 30 s to establish that the pressure does not fall and that there are no leaks. The pressure may exceed p_h by 3 % of p_h or by 10 bar, whichever is the lower. After the test, the gas cylinder shall show no visible permanent deformation.

11.2.2 Volumetric-expansion test

The water pressure in the gas cylinder shall be increased at a controlled rate until the test pressure, p_h, is reached.

The gas cylinder shall remain under pressure p_h for at least 30 s and the total volumetric expansion measured. The pressure shall then be released and the volumetric expansion remeasured.

The gas cylinder shall be rejected if it shows a permanent expansion (i.e. volumetric expansion after the pressure has been released) in excess of 5 % of the total volumetric expansion measured at the test pressure, p_h.

The total and permanent expansion readings shall be recorded, together with the corresponding serial number of each gas cylinder tested, so that the elastic expansion (i.e. total expansion less permanent expansion) under the test pressure can be established for each gas cylinder.

11.3 Hardness test

A hardness test in accordance with ISO 6506-1 (Brinell), ISO 6508-1 (Rockwell B) or another, equivalent, method (e.g. the rebounding-ball, coefficient of restitution method) shall be carried out by the manufacturer. The hardness values thus determined shall be within the limits specified by the gas cylinder manufacturer for the material and manufacturing route, dependent upon the final treatment used for the production of the gas cylinder. The values may be expressed in Brinell, Rockwell B or other, equivalent, units.

By agreement with the Inspection Body, the hardness test may be replaced by an electrical-conductivity test.

11.4 Leakage testing

The manufacturer shall employ such manufacturing techniques and apply such tests as will demonstrate to the satisfaction of the Inspection Body that the gas cylinders do not leak.

11.5 Examination for neck folds

Each gas cylinder shall be examined for neck folds by a suitable means (e.g. scope, tactile, ultrasonic, etc). Severe folds might adversely affect the performance of the gas cylinder or the integrity of the gas cylinder. To assess the effect of any severe folds in the gas cylinder, gas cylinders with such folds shall be used for batch pressure-cycling and burst tests. In addition, gas cylinders with folds that exceed two continuous threads shall be condemned.

Folds that do not adversely affect the performance or the integrity of the gas cylinder may be machined until the lines are no longer visible (i.e. repaired). Gas cylinders with folds running into two or less threads (as shown on the left-hand side of Figure 8) may be repaired. If a gas cylinder is repaired in this way, the thread shall still meet the minimum requirements for length and number as per the relevant standard. In addition, the remaining thickness of the machined area and the thread′s characteristics shall be at least those required to pass all necessary testing. The whole internal shoulder area shall be re-inspected to verify that folding or its lines have been removed.

11.6 Marking verification

Gas cylinder markings shall be verified to be in accordance with Clause 13.

11.7 Aluminium alloy gas cylinder surface features at time of manufacture

11.7.1 Requirements

At the time of manufacture, finished gas cylinders shall have no feature which adversely affects gas cylinder performance or integrity (see 8.4 and specific unacceptable imperfections in other subclauses in Clause 8 and in this subclause). Such features are considered to be defects.

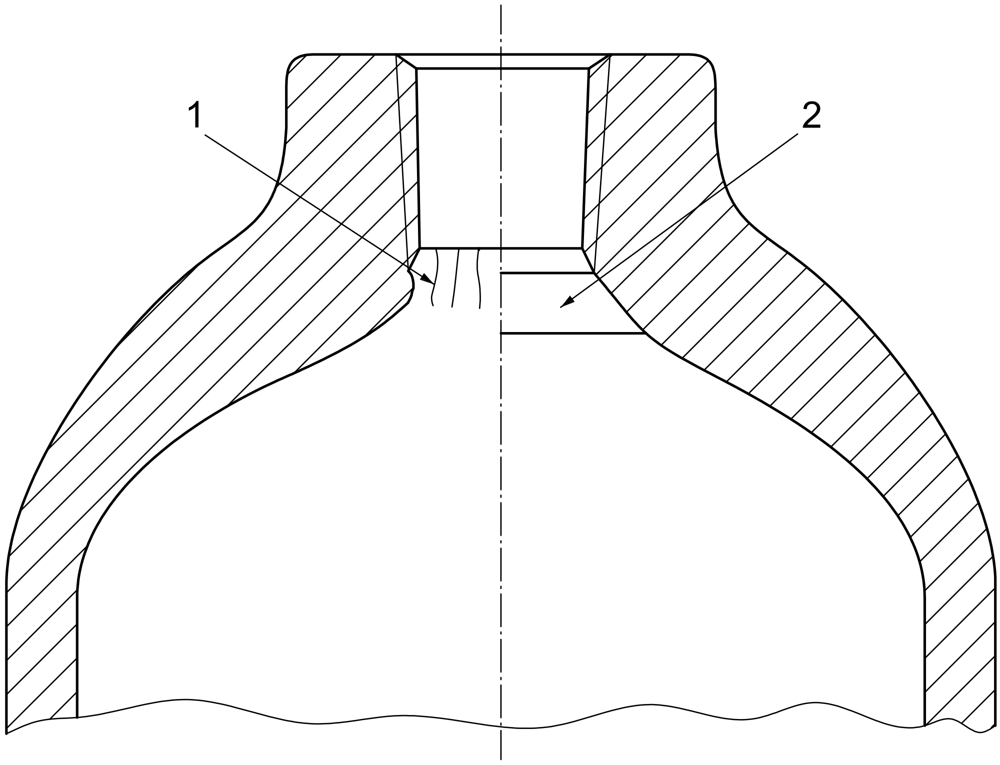
At the time of manufacture, finished gas cylinders shall have no surface imperfections which would be considered to be unacceptable according to ISO 10461.

The integrity and performance of gas cylinders with questionable features identified by the Inspection Body shall be verified by testing samples from the batch in accordance with the test procedures and criteria in this International Standard. The batch shall be condemned if the tests show unacceptable results and deemed acceptable if the tests show acceptable results.

Surface imperfections may be dressed or repaired provided the gas cylinder wall thickness meets or exceeds the thickness required by this International Standard.

11.7.2 Imperfection considerations

Annex F lists and describes gas cylinder surface imperfections and gives the criteria by which they may be assessed. Those imperfections which are acceptable should be agreed upon between the manufacturer and purchaser. Purchasers may specify surface imperfection criteria such as those listed in Annex F or establish their own criteria, provided such criteria do not conflict with the requirements specified in 11.7.1.



Key

1 folds

2 folds machined away

Figure 8 — Example of gas cylinder neck folds before and after machining

12 Certification

Each satisfactory batch of gas cylinders shall be covered by a certificate, signed by a party designated by the relevant competent authority, to the effect that the gas cylinders meet the requirements of this International Standard in all respects. An example of a suitably worded certificate is given in Annex D.

Copies of the certificate shall be issued to the manufacturer. The original certificate shall be retained by the Inspection Body and the manufacturer's copies shall be retained by the manufacturer in accordance with the regulations of the relevant competent authority.

13 Marking

Each cylinder shall be permanently marked on the shoulder in accordance with ISO 13769 or in accordance with the relevant marking regulations of the country or countries of use.

NOTE Attention is drawn to the possible existence in relevant regulations of marking requirements that might override the requirements given in this International Standard.

Annex A
(normative)

Corrosion tests

A.1 Tests for assessing susceptibility to intercrystalline corrosion

A.1.1 Principle

The method described below consists of simultaneously immersing specimens taken from the finished gas cylinder under test in a corrosive solution and examining them after a specified etching time in order to detect any signs of intercrystalline corrosion and to determine the nature and degree of such corrosion. The propagation of intercrystalline corrosion is determined metallographically on polished surfaces cut transversely to the etched surface.

A.1.2 Taking specimens

Take specimens from the head, body and base of the gas cylinder (see Figure A.1) so that the tests with the solution specified in A.1.4.1 can be carried out on metal from three parts of the gas cylinder.

Each specimen shall be of the dimensions and general shape indicated in Figure A.2.

Faces $a_1a_2a_3a_4$, $b_1b_2b_3b_4$, $a_1a_2b_2b_1$ and $a_4a_3b_3b_4$ shall all be sawn with a band saw and then carefully trimmed with a fine file. Surfaces $a_1a_4b_4b_1$ and $a_2a_3b_3b_2$, which correspond respectively to the inner and outer faces of the gas cylinder, shall be left in their rough state.

A.1.3 Preparation of surface before corrosive etching

A.1.3.1 Reagents

A.1.3.1.1 **Nitric acid** (HNO_3), analytical grade, density 1,33 g/cm^3.

A.1.3.1.2 **Hydrofluoric acid** (HF), analytical grade, density 1,14 g/cm^3 (at 40 %).

A.1.3.1.3 **Deionized or distilled water**.

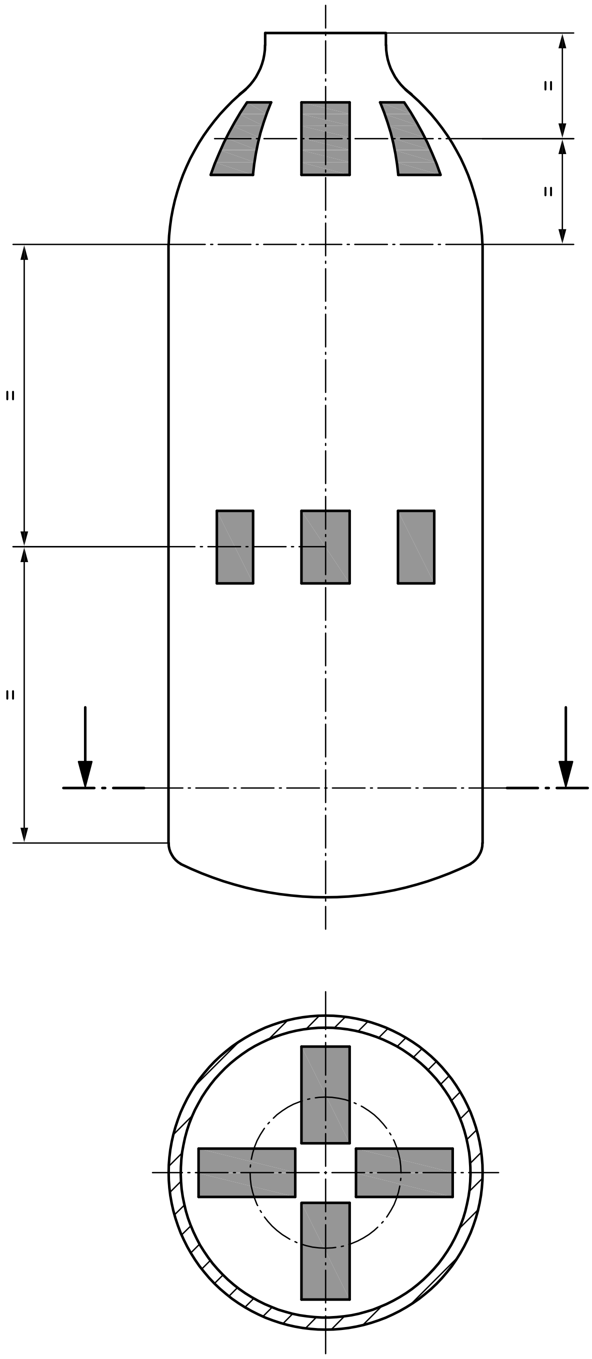
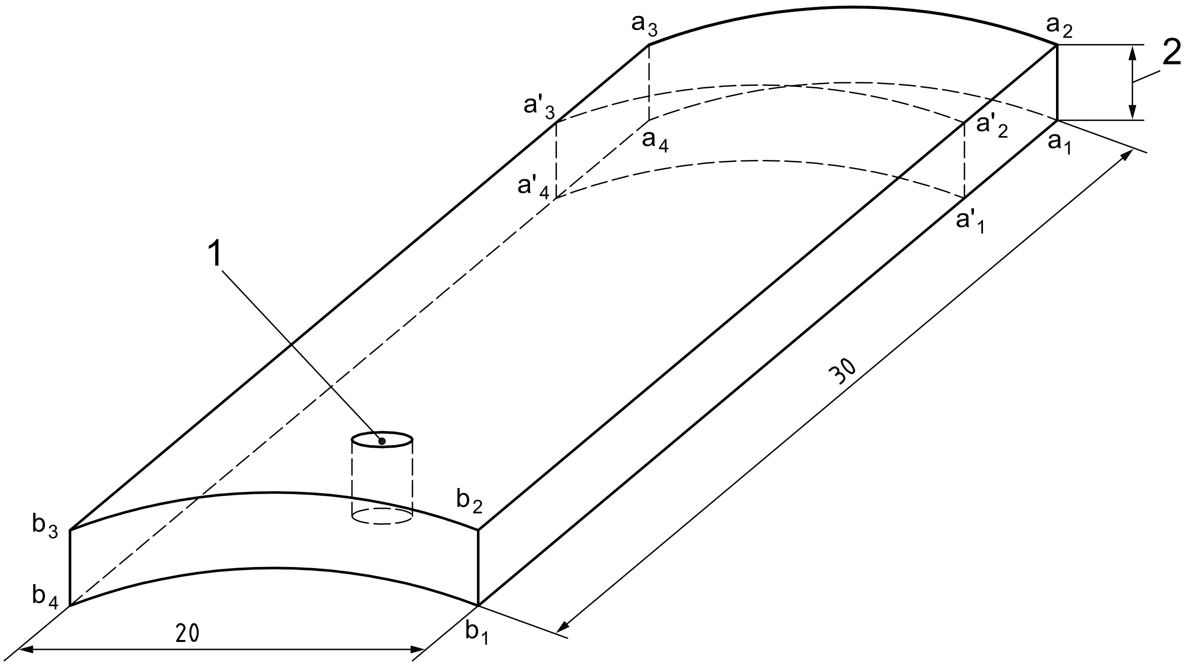


Figure A.1 — Locations of specimens

Dimensions in millimetres
±10 %



Key

1 hole, ∅ 3 mm

2 thickness of gas cylinder wall

Figure A.2 — Specimen shape and dimensions

A.1.3.2 Method

Prepare the following solution in a beaker:

HNO_3 (A.1.3.1.1):	63 cm^3
HF (A.1.3.1.2)]:	6 cm^3
H_2O (A.1.3.1.3):	931 cm^3

Bring the solution to a temperature of 95 °C.

Treat each specimen, suspended on a wire made of aluminium or another inert material, in this solution for 1 min.

Wash in running water and then in deionized or distilled water (A.1.3.1.3).

Immerse each specimen in nitric acid (A.1.3.1.1) for 1 min at room temperature to remove any copper deposit which may have formed.

Rinse in deionized or distilled water.

To prevent oxidation of specimens, plunge them, as soon as they have been prepared, into the corrosion bath intended for them (see A.1.4.1).

A.1.4 Performance of test

A.1.4.1 Corrosive solution

The corrosive solution to be used shall contain 57 g/l of sodium chloride and 3 g/l of hydrogen peroxide.

A.1.4.2 Preparation of the corrosive solution

A.1.4.2.1 Reagents

A.1.4.2.1.1 Sodium chloride (NaCl), crystallized, analytical grade.

A.1.4.2.1.2 Hydrogen peroxide (H_2O_2), 100- to 110-volume.

A.1.4.2.1.3 Potassium permanganate ($KMnO_4$), analytical grade.

A.1.4.2.1.4 Sulfuric acid (H_2SO_4), analytical grade, density 1,83 g/cm^3.

A.1.4.2.1.5 Deionized or distilled water.

A.1.4.2.2 Titration of hydrogen peroxide

Since hydrogen peroxide is not very stable, it is essential to check its titre before use. To do this, take 10 cm^3 of hydrogen peroxide (A.1.4.2.1.2) with a pipette, dilute to 1 000 cm^3 (in a volumetric flask) with deionized or distilled water (A.1.4.2.1.5), thus obtaining a hydrogen peroxide solution which will be called solution C. Using a pipette, place in a conical flask

10 cm^3 of hydrogen peroxide solution C, and

approximately 2 cm^3 of sulfuric acid (A.1.4.2.1.4).

Use a 1,859 g/l solution of potassium permanganate (A.1.4.2.1.3) for the titration. The potassium permanganate itself acts as an indicator.

A.1.4.2.3 Explanation of titration

The reaction of potassium permanganate with hydrogen peroxide in a sulfuric acid medium is described by the following equation:

$$2KMnO_4 + 5H_2O_2 + 3H_2SO_4 = K_2SO_4 + 2MnSO_4 + 8H_2O + 5O_2$$

which gives the equivalence: 316 g of $KMnO_4$ = 170 g of H_2O_2.

Therefore 1 g of pure hydrogen peroxide reacts with 1,859 g of potassium permanganate, hence the use of a 1,859 g/l solution of potassium permanganate, which neutralizes, volume for volume, a 1 g/l solution of hydrogen peroxide. Since the hydrogen peroxide was diluted 100× to begin with, the 10 cm^3 of solution C taken represents 0,1 cm^3 of the original hydrogen peroxide.

By multiplying by 10 the number of cubic centimetres of potassium permanganate solution used for the titration, the titre, T, of the original hydrogen peroxide, in grams per litre, is obtained.

A.1.4.2.4 Preparation of the solution

Method for 10 litres:

Dissolve 570 g of sodium chloride (A.1.4.2.1.1) in deionized or distilled water (A.1.4.2.1.5) to obtain a total volume of about 9 litres. Add the quantity of hydrogen peroxide (A.1.4.2.1.2) calculated below. Mix and then make up the volume to 10 litres with deionized or distilled water.

Calculate the volume of hydrogen peroxide to be put into the solution as follows.

Quantity of pure hydrogen peroxide required: 30 g.

If the hydrogen peroxide contains T grams of H_2O_2 per litre, the volume required, expressed in cubic centimetres, will be:

$$\frac{1\,000 \times 30}{T}$$

A.1.4.3 Etching procedure

A.1.4.3.1 Place the corrosive solution in a crystallizing dish (or possibly a large beaker), itself placed in a water bath. Keep the water bath stirred with a magnetic stirrer and regulate the temperature with a contact thermometer.

Either suspend the specimen in the corrosive solution by a wire made of aluminium (or another inert material) or place it in the solution so that it rests only on its corners, the second method being the preferred one. Etch the specimen for 6 h with the temperature held at (30 ± 1) °C. Take care to ensure that the volume of solution used is at least 10 cm^3 per square centimetre of specimen surface.

After etching, wash the specimen in water, immerse it for about 30 s in 50 % dilute nitric acid, wash it again in water and dry it with compressed air.

A.1.4.3.2 A number of specimens may be etched at the same time provided they are of the same type of alloy and that they are not in contact. The minimum volume of reagent per unit of specimen surface area shall be adhered to.

A.1.5 Preparation of specimens for examination

A.1.5.1 Apparatus and materials required

A.1.5.1.1 **Casting dishes**, with, for example, the following dimensions:

external diameter: 40 mm;

height: 27 mm;

wall thickness: 2,5 mm.

A.1.5.1.2 **Epoxy casting resin plus hardener**, or an equivalent system.

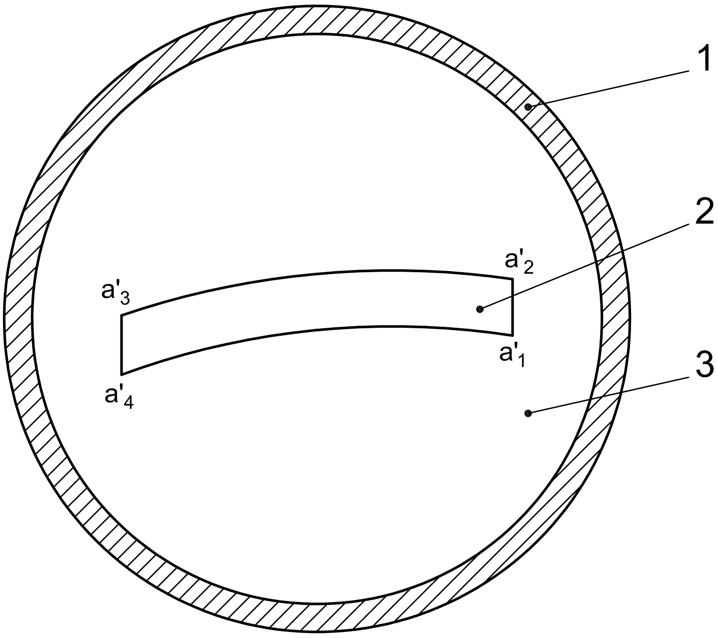
A.1.5.2 Method

Place each specimen vertically in a casting dish (A.1.5.1.1) so that it rests on face $a_1a_2a_3a_4$. Pour around it a mixture of the epoxy resin and hardener (or equivalent) (A.1.5.1.2) in the appropriate proportions.

Remove a certain amount of material from the face $a_1a_2a_3a_4$, preferably with a lathe, so that the section $a'_1a'_2a'_3a'_4$, when examined under the microscope, cannot show corrosion from face $a_1a_2a_3a_4$. The distance between faces $a_1a_2a_3a_4$ and $a'_1a'_2a'_3a'_4$, i.e. the thickness removed by the lathe, shall be at least 2 mm (see Figures A.2 and A.3).

Alternatively, prepare a section by sawing through plane $a'_1a'_2a'_3a'_4$ (see Figure A.2) to remove a specimen between 5 mm and 10 mm thick (i.e. such that the distance from a'_1 to a_1 is between 5 mm and 10 mm). Mount this specimen in thermosetting or thermoplastic mounting compound with face $a'_1a'_2a'_3a'_4$ exposed to allow mechanical polishing.

Polish the section for examination mechanically with abrasive paper, a diamond compound and/or magnesia polishing compound.



Key

1 casting mould

2 test specimen

3 epoxy resin and hardener

Figure A.3 — Specimen in casting dish

A.1.6 Micrographic examination of specimens

The examination is intended to assess the degree of penetration of the intercrystallization corrosion into each of the two faces which make up the outer and inner surfaces of the gas cylinder.

First examine the section at low magnification (e.g. ×40) in order to locate the most corroded areas, and then at a higher magnification, usually about ×300, in order to assess the nature and extent of the corrosion.

A.1.7 Interpretation of micrographic examination

a) For alloys with an equiaxed crystal structure, the depth of corrosion shall not exceed the greater of the following two values:

   — three grains in the direction perpendicular to the face examined;

   — 0,2 mm.

   But in no case shall the depth exceed 0,3 mm.

   However, it is permissible for these values to be exceeded locally, provided they are not exceeded in more than four fields of examination at ×300 magnification.

b) For alloys with a crystal structure oriented in one direction through cold working, the depth of corrosion into each of the two faces which make up the internal and external surfaces of the gas cylinder shall not exceed 0,1 mm.

A.2 Test for assessing susceptibility to stress corrosion

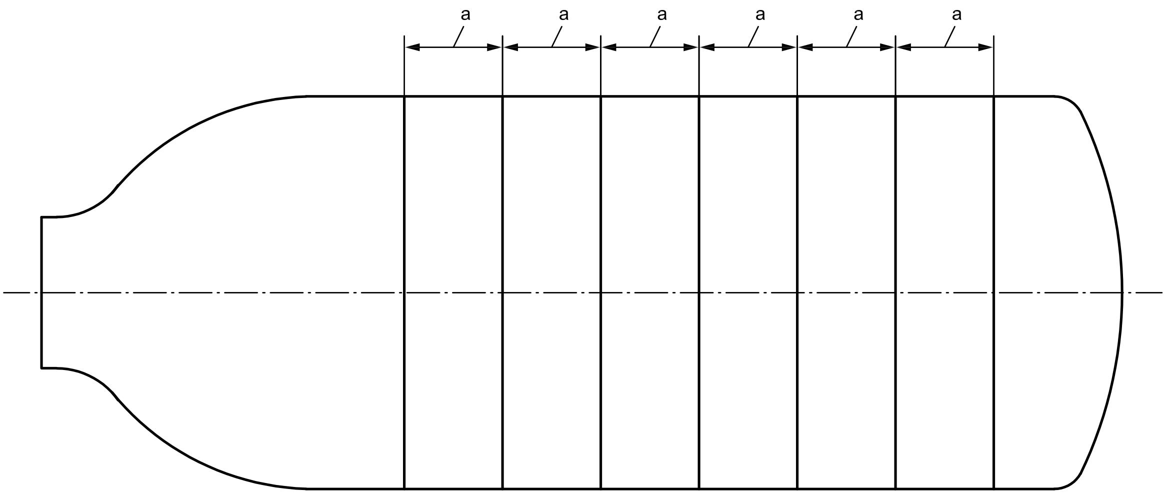
A.2.1 Principle

The method described below involves subjecting rings cut from the cylindrical part of a gas cylinder to stress and immersing them in brine for a specified period, followed by removal from the brine and exposure of the rings to the air for a longer period, this cycle being repeated for 30 days. If there are no cracks after the period of 30 days, the alloy is considered suitable for the manufacture of gas cylinders.

A.2.2 Test specimens

Cut six rings with a width of 4 × the actual wall thickness or 25 mm, whichever is the greater, from the cylindrical part of the gas cylinder (see Figure A.4). Make a 60° cut-out in each specimen and subject them to stress by means of a threaded bolt and two nuts (see Figure A.5).

Neither the inner nor the outer surfaces of the specimens shall be machined.



[a] 4 × the actual wall thickness, in millimetres, or 25 mm, whichever is the greater.

Figure A.4 — Specimen ring locations

A.2.3 Surface preparation before corrosion test

Remove all traces of grease, oil and adhesive used with stress gauges (see A.2.4.2) with a suitable solvent.

A.2.4 Performance of the test

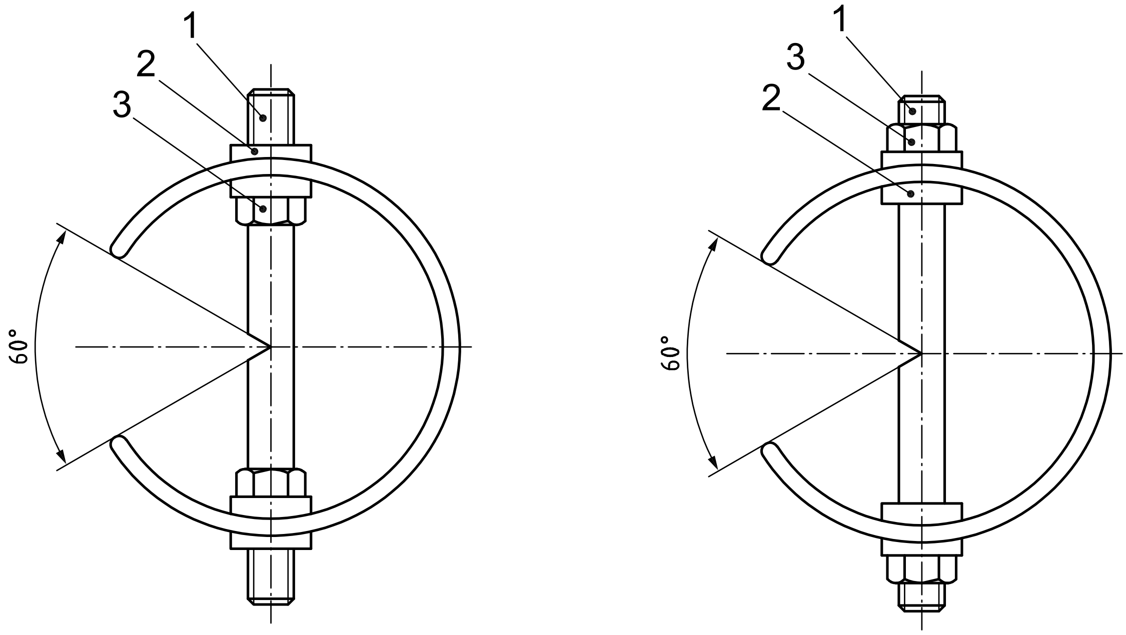
A.2.4.1 Preparation of corrosive solution

Prepare the brine by dissolving (3,5 ± 0,1) parts by mass of sodium chloride in 96,5 parts by mass of water.

The pH of the freshly prepared solution shall be in the range 6,4 to 7,2. The pH may be corrected only by using dilute hydrochloric acid or dilute sodium hydroxide.

The solution shall not be topped up by adding the salt solution prepared in A.1.4.2.4, but only by adding distilled water up to the initial level in the vessel. Topping up may be carried out daily if required.

The solution shall be completely replaced every week.



a) Stressed internally

b) Stressed externally

Key

1 threaded bar

2 insulating bush

3 nut

Figure A.5 — Stressed specimens

A.2.4.2 Applying the stress to the rings

Three of the rings shall be compressed so that the outer surface is under tension. The other three rings shall be expanded so that the inner surface is under tension.

The rings shall be stressed to a maximum value given by:

Maximum stress $= R_{eg} \times F$

where

R_{eg} is the guaranteed minimum 0,2 % proof strength, in megapascals;

F is the design stress factor (variable).

The actual stress may be measured by electric stress gauges.

The diameter of the ring corresponding to the required maximum stress can be calculated using the following equation:

$$D' = D \pm \frac{\pi R (D - t)^2}{4Etz}$$

where

D' is the outside diameter of the ring when compressed (or when expanded), in millimetres;

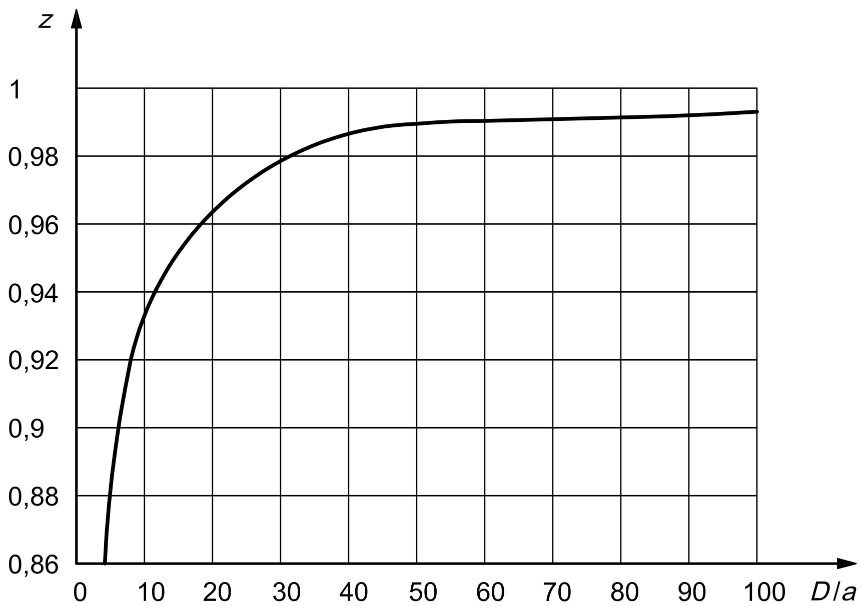
D is the outside diameter of the gas cylinder, in millimetres;

t is the gas cylinder wall thickness, in millimetres;

R is the maximum stress value, $R_{eg} \times F$, in megapascals;

E is the modulus of elasticity, in megapascals (= 70 MPa approximately);

z is a correction factor (see Figure A.6).



Key

D outside diameter of gas cylinder

t actual wall thickness of gas cylinder

z correction factor

Figure A.6 — Correction factor, z

It is essential for the nuts and bolts to be electrically insulated from the rings and protected from corrosion caused by the salt solution.

Immerse the six rings completely in the salt solution for 10 min. Then remove them from the solution and expose them to the air for 50 min.

Repeat this cycle for 30 days or until a ring breaks, whichever happens first.

Inspect the specimens visually for any cracks.

A.2.5 Interpretation of results

The alloy shall be considered acceptable for the manufacture of gas cylinders if none of the rings subjected to stress has developed any cracks visible to the naked eye, or visible at low magnification (×10 to ×30), at the end of the 30-day test period.

A.2.6 Possible metallographic examination

A.2.6.1 In the event of doubt about the presence of cracks (e.g. if a line of pitting is present), the uncertainty may be removed by means of an additional metallographic examination of a section taken perpendicular to the axis of the ring in the suspect area. A comparison is made of the form (inter- or trans-crystalline) and depth of penetration of the corrosion on the faces of the ring subject to tensile and compressive stress.

A.2.6.2 The alloy shall be considered acceptable if the corrosion on both faces of the ring is similar.

If, however, the face of the ring under tension reveals intercrystalline cracks which are clearly deeper than those in the face under compression, the ring shall be considered to have failed the test.

A.2.7 Test report

The test report shall state at least the following details:

a) the name of the alloy and/or its standard number;

b) the composition limits of the alloy;

c) the actual analysis of the cast from which the gas cylinders were manufactured;

d) the actual mechanical properties of the alloy, together with the minimum mechanical-property requirements;

e) the result of the test.

Annex B
(normative)

Test method to determine the sustained-load cracking resistance of aluminium alloy gas cylinders

B.1 Principle

A fatigue-precracked specimen is loaded by a constant-load or constant-displacement method to a stress intensity factor, K_{IAPP}, equal to a defined value. The specimen is kept in the loaded condition for a specified time at a specified temperature. After this test period, the specimen is examined to assess whether the initial fatigue crack did or did not grow.

If the test specimen exhibits less than or equal to a specified amount of crack growth, then the material is considered suitable for gas cylinders with respect to the sustained-load cracking resistance requirement.

B.2 General

This method covers the determination of the sustained-load cracking resistance for aluminium alloy gas cylinders.

Following the initial qualification for resistance to sustained-load cracking, this procedure shall only be repeated if any of the conditions a), b), c) or d) listed in 9.1 apply.

Testing shall be conducted using the applicable requirements of ISO 7539-6 and the additional requirements specified in this International Standard. Requirements given in ISO 7539-6 for corrosive environments need not be satisfied.

Gas cylinders with nominal neck and shoulder wall thicknesses ≤ 7 mm are exempt from sustained-load cracking tests. The Inspection Body shall ensure that the neck and shoulder wall thicknesses of the actual gas cylinders reasonably represents the quoted nominal figure. Figure B.1 illustrates the neck and shoulder thicknesses.

B.3 Terms and definitions and symbols

For the purposes of this annex, the terms and definitions and symbols given in ISO 7539-6 and the following apply.

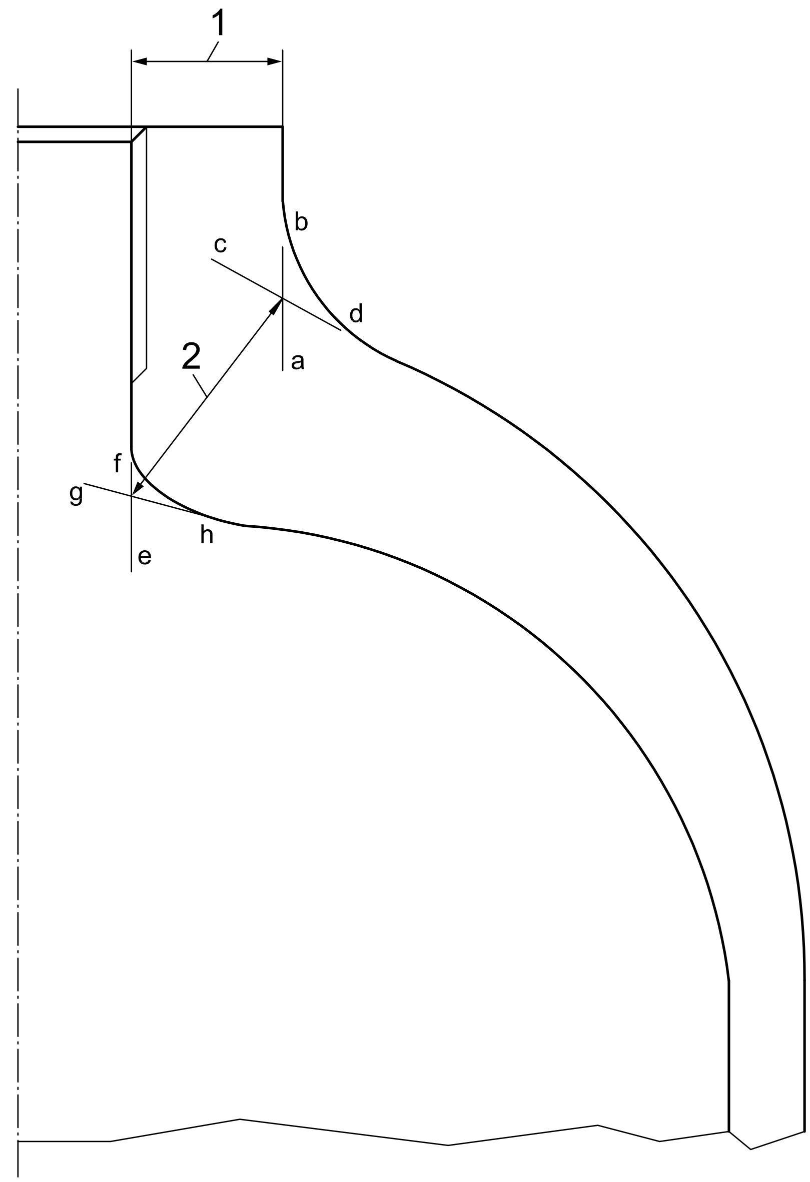
SLC sustained-load cracking

K_{IAPP} applied elastic-stress intensity factor, in megapascal root metres (MPa·√m)

V crack-mouth opening displacement (CMOD), in millimetres, defined as the mode 1 (also called opening-mode) component of crack displacement due to elastic and plastic deformation, measured at the location on a crack surface that has the greatest elastic displacement per unit load

E modulus of elasticity, in megapascals

R_{eSLC} average of the measured yield strength, in megapascals, of two specimens, from the test gas cylinder, representing the SLC test specimen locations at room temperature (for locations of specimens, refer to B.4.3)



Key

1 nominal neck thickness

2 nominal shoulder thickness

NOTE ab, cd, ef and gh are tangents starting at intersecting surfaces.

Figure B.1 — Illustration of neck and shoulder thickness

B.4 Specimen configurations and numbers of tests

B.4.1 One of the following specimen geometries, or a combination of them, shall be used for the tests:

— compact tension-test (CTS) specimen, as shown in Figure 3 in ISO 7539-6:2011;

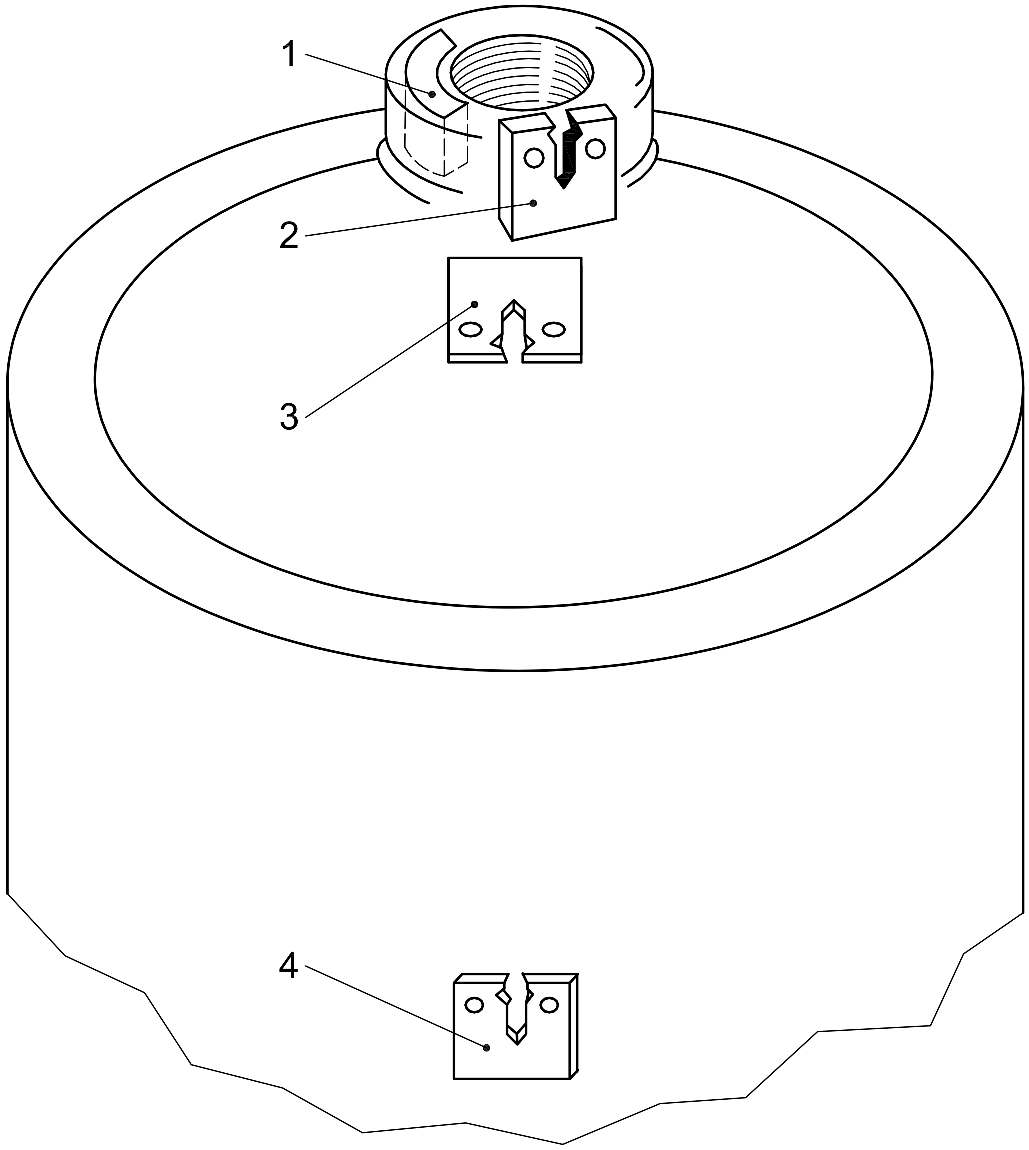
— double cantilever beam (DCB) specimen, as shown in Figure 4 in ISO 7539-6:2011;

— modified wedge opening loaded (modified WOL) specimen, as shown in Figure 5 in ISO 7539-6:2011;

— C-shaped specimen, as shown in Figure 6 in ISO 7539-6:2011.

B.4.2 Specimen orientation shall be Y-X or Y-Z as shown in Figure B.2 below.

B.4.3 At least three specimens from the gas cylinder wall and, if possible, three specimens from the shoulder and three specimens from the neck shall be tested. At each location, the three specimens shall be taken as close to each other as possible. One specimen from each location shall be used for SLC testing and two from each location for tensile testing.



Key

1 Y-Z neck specimen

2 Y-X neck specimen

3 Y-X shoulder specimen, taken as close as possible to the neck with the notch tip towards the neck, as shown

4 Y-X cylinder wall specimen

Figure B.2 — Orientation of neck, shoulder and gas cylinder wall specimens

B.4.4 Flattening of test specimens is not allowed.

B.4.5 If test specimens with the thickness necessary to meet the B.6.7 validity requirements cannot be obtained from the specified location or locations, then the thickest possible specimens shall be tested. The specimens shall be taken when the mechanical properties of the gas cylinder have been fully developed, but before any external machining of the neck/shoulder area.

B.4.6 When it is impossible to obtain full-size tensile specimens, small-size specimens in accordance with ISO 6892-1 are permitted for the determination of the yield strength.

B.5 Fatigue precracking

All requirements specified in Clause 6 of ISO 7539-6:2011 shall be satisfied, except that the fatigue crack length (a, in mm) requirement in 6.4 of ISO 7539-6:2011 shall be given by the following equation:

$$a \geq 1{,}27\left(\frac{K_{\mathrm{IAPP}}}{R_{\mathrm{egSLC}}}\right)^2 \times 1\,000$$

B.6 Specimen testing procedure

B.6.1 All requirements specified in Clause 7 of ISO 7539-6:2011 shall be satisfied, except that the requirements in the following subclauses need not be satisfied:

7.2.2, 7.2.6, 7.5.1, 7.5.2, 7.5.4, 7.5.5

B.6.2 Load the fatigue-precracked specimens to a stress intensity factor, K_{IAPP}, determined from the following equation:

$$K_{\mathrm{IAPP}} = 0{,}056 R_{\mathrm{egSLC}}$$

Specimens shall be loaded by a suitable constant-displacement or constant-load method.

B.6.3 For specimens loaded by a constant-displacement method, the loading shall be determined by either the non-monitored-load method or the monitored-load method and shall meet the following requirements.

a) For the non-monitored-load method:

1) At the end of the test, record the crack mouth opening displacement (CMOD) before unloading.

2) Unload the specimen.

3) Reload the specimen up to the measured CMOD in a device suitable for load measurement. Record the load and use this load in the K_{IAPP} calculations. This calculated K_{IAPP} shall be equal to or greater than the K_{IAPP} value calculated from B.6.2.

b) For the monitored-load method:

1) Use the final load at the end of the test period in the calculation of K_{IAPP}.

2) This calculated value of K_{IAPP} shall be equal to or greater than the K_{IAPP} value calculated from B.6.2.

B.6.4 For the constant-displacement method, the crack mouth opening displacement, V, shall be determined as follows.

a) For testing of CTS specimens at a constant-displacement loading, use the following equations to determine V:

$$V = \frac{K_{\text{IAPP}} \times \sqrt{W}}{0{,}032 \times E \times f(x) \times \sqrt{B / B_{\text{N}}}}$$

$$f(x) = \frac{2{,}24 \times (1{,}72 - 0{,}9x + x^2) \times \sqrt{1 - x}}{9{,}85 - 0{,}17x + 11x^2}$$

$$x = \frac{a}{W}$$

b) For testing of C-shaped specimens at a constant-displacement loading, use the following equations:

For specimens with $x/W = 0$:

$$V = \frac{K_{\text{IAPP}} \times \sqrt{W} \times P_1 \times [0{,}43(1 - r_1/r_2) + Q_1]}{0{,}032 \times E \times Y}$$

For specimens with $x/W = 0{,}5$:

$$V = \frac{K_{\text{IAPP}} \times \sqrt{W} \times P_2 \times [0{,}45(1 - r_1/r_2) + Q_2]}{0{,}032 \times E \times Y}$$

where

W effective width of the specimen measured from the back face to either the face containing the notch, or the loading plane, depending on the specimen geometry;

B side-to-side dimension of the specimen being tested;

B_{N} minimum side-to-side dimension between the notches in side-grooved specimens;

Y is as defined in ISO 7539-6:2011, Figure 14;

$P_1 = (1 + a/W)/(1 - a/W)^2$;

$Q_1 = 0{,}542 + 13{,}137(a/W) - 12{,}316(a/W)^2 + 6{,}576(a/W)^3$;

$P_2 = (2 + a/W)/(1 - a/W)^2$;

$Q_2 = 0{,}399 + 12{,}63(a/W) - 9{,}838(a/W)^2 + 4{,}66(a/W)^3$.

c) The stress intensity factor equations provided in ISO 7539-6 shall be used in testing of DCB and modified-WOL specimens in the constant-displacement mode.

B.6.5 For the constant-loading method:

a) For testing of DCB specimens at a constant load, use the following equation (see Reference [7] for further information):

$$K_{\text{IAPP}} = \left(\frac{P_a}{BH^{3/2}}\right)\left(3{,}46 + \frac{2{,}38H}{a}\right)$$

where

B side-to-side dimension of the specimen being tested;

P_a applied load.

The above equation shall satisfy the following validity requirements.

$2 \leq a/H \leq 10$

$W \geq a + 2H$

b) For testing of CTS, modified-WOL and C-shaped specimens at a constant load, the stress intensity factor equations provided in ISO 7539-6 shall be used.

B.6.6 The loaded specimens shall be tested for 90 days at (23 ± 5) °C or for 30 days at (80 ± 5) °C.

B.6.7 The validity condition given in 7.6.6, item e), of ISO 7539-6:2011 shall be replaced by the following condition.

$$a, B, B_N, (W - a) \geq 1{,}27 \left(\frac{K_{IAPP}}{R_{egSLC}} \right)^2 \times 1\,000$$

All specimens shall meet the validity requirements except as exempted in B.4.5.

B.6.8 If the additional test referred to in B.7.4 is required, then repeat the entire procedure using only constant-load conditions as described in B.6.5 for a period of 180 days at room temperature.

B.7 Crack growth examination

B.7.1 After the specified test period, unload the specimen and fatigue the specimen at a maximum stress intensity not exceeding $0{,}6K_{IAPP}$ until the crack advances by at least 1 mm. After this fatigue cracking, break open the specimen.

B.7.2 Measure the distance between the prefatigue crack and the postfatigue crack using a scanning electron microscope (SEM). Take the measurements perpendicular to the prefatigue and postfatigue cracks at locations representing 25 % of B, 50 % of B and 75 % of B. Calculate the average of these three values.

B.7.3 If the average measured distance between the two fatigue cracks does not exceed 0,16 mm, the specimen passes the test. If all specimens pass, the alloy/process is considered to be qualified (see also Clause B.8).

B.7.4 If the average measured values from B.7.3 exceed 0,16 mm, the alloy/process may be qualified if, when subjected to the additional test described in B.6.8, the average measured distance between the two fatigue cracks shall not exceed 0,3 mm. B.7.1 and B.7.2 shall also apply.

B.8 Gas cylinder thickness qualification

If the validity requirements of B.6.7 are not met, then the material is suitable up to the maximum thickness of the gas cylinder location from where the specimens were taken, provided the specimens meet the other requirements of this test method. The material is suitable for all thicknesses if the specimens meet the validity requirements of B.6.7 as well as the other requirements of this test method.

B.9 Test report

The information required in ISO 7539-6:2011, Clause 8, with the exception of 8.5, shall be reported. The report shall indicate if the validity criteria are met or not and shall include an SEM micrograph as per B.7.2. The test report shall be kept on file permanently as a record that the gas cylinder alloy/process has been tested and found acceptable.

Annex C
(informative)

Typical type approval certificate

This annex provides an example of a suitable form of a type approval certificate. Other formats are also acceptable.

TYPE APPROVAL CERTIFICATE

Issued by .... *(Inspection Body)*

....

applying International Standard ISO 7866

concerning

SEAMLESS ALUMINIUM GAS CYLINDERS

Approval No.: .... Date: ....

Test reports (specified documents): ....

Type of gas cylinder: ....

[Description of the family of gas cylinders (drawing No.) which has received type approval]

p_h .... bar D_{min} .... mm D_{max} .... mm a' .... mm

Shape of base .... b .... mm

L_{min} .... mm L_{max} .... mm V_{min} .... litres V_{max} .... litres

Material and heat treatment: ....

Material and characteristics: Material: .... R_{eg} .... MPa R_{mg} .... MPa

Manufacturer or agent: ....

(Name and address of manufacturer or manufacturer's agent)

....

....

All information may be obtained from:

....

(Name and address of approving body)

....

....

The type approval batch has been tested in accordance with ISO 7866 and the results are in compliance with ISO 7966 and the approved manufacturing drawings.

Date: ....   Place:...

(Signature of Inspector)

Annex D
(informative)

Acceptance certificate

This annex provides an example of a suitable form of an acceptance certificate. Other formats are also acceptable.

ACCEPTANCE CERTIFICATE

Acceptance certificate No. .... **for seamless aluminium gas cylinders**

A consignment of .... gas cylinders consisting of .... test batches has been inspected and tested for .... in accordance with ISO 7866:

Designation or type of gas: ....

Manufacturer's Nos.: .... to ....

Owner's Nos.[1]: .... to ....

Manufacturer: .... Manuf. order No: ....

Address: ....

Country: .... Date: ....

Owner/customer[2]: .... Purchase order No.: ....

Address: ....

Country: .... Date: ....

TECHNICAL DATA

Water capacity: nominal[2] .... litres
minimum[2] .... litres

Nominal length (without cap and without valve) .... mm

Test pressure, p_h: .... bar

Outside diameter, D: .... mm

Working pressure[2] at 15 °C, p_{15}: .... bar

Min. wall thickness, a: .... mm

Max. filling charge[2]: .... kg

Drawing No.: ....

Material: ....

Specified analysis[3]	Si %	Fe %	Cu %	Mn %	Mg %	Cr %	Ni %	Zn %	Ti %	Zr %	Pb %	Others
Max.												
Min.												

Heat treatment[2]: ....

Stamp markings[3]: ....

Date: ....

....
The manufacturer

1) If required by customer.
2) Delete as applicable.
3) To be quoted or drawing to be attached.

ACCEPTANCE TESTS

1. Measurements taken on one representative gas cylinder of the batch[1)]:

Test No. or batch No. or gas cylinder No.	Covering serial Nos. .... to	Water capacity (litres)	Mass empty (kg)	Min. measured thickness (mm)	
				wall	**base**

2. Mechanical tests[1)]:

Test No.	Cast No.	Tensile testing			Hardness	Bend or flattening test
		Yield strength, R_{ea} MPa	**Tensile strength**, R_{ma} MPa	**Elongation after fracture**, A %	HB	(180° without cracking)
Min. values:						

This is to certify that the gas cylinders covered by this Acceptance Certificate have passed the hydraulic pressure test and all the other tests as required in Clauses 10 and 11 of ISO 7866:2012 and they are in full accordance with that International Standard.

Special remarks: ....

....

....

On behalf of: ....

....

.

Date: ....

(Signature of Inspector)

1) Need not be filled in if test reports are attached.

Annex E
(normative)

Specific requirements for gas cylinders made of high-strength and/or low-elongation aluminium alloy

E.1 Field of application

This annex applies to aluminium alloys of design yield strength greater than 380 MPa and those alloys for which the elongation after fracture is less than 12 %. Alloys of lower elongation after fracture which have higher strength (compared to 5000-series or 6000-series alloys) may be accepted, provided an adequate fracture toughness and an adequate resistance to crack propagation under a cycling stress are demonstrated.

This requires up to two types of test, both of which use an artificial flaw produced by machining.

One test, known as the leak before burst (LBB) test, aims at establishing that, when the gas cylinder is cycled or burst at a pressure of at least 2/3 p_h, the critical defect size for which rupture would occur by leaking (and not bursting) is above a specified value.

The other test, if applicable, aims at establishing that the residual cycling life at p_h of a gas cylinder bearing a specified defect remains above a specified value. This test is known as the flawed gas cylinder cycling (FCC) test.

NOTE A similar approach has been used for gas cylinders made of high-strength steels (see ISO 9809-2).

Clauses E.3 and E.4 specify the test procedures. Clause E.5 specifies the frequency of testing. Clause E.6 specifies additional manufacturing requirements for alloy 2001. The applicable elongation after fracture requirements are also specified.

E.2 General requirements

All alloys of design yield strength greater than 380 MPa shall be prototype-tested with the LBB test.

If the elongation after fracture is below 12 % at all design yield strength levels, then both the LBB and the FCC tests described below shall be performed.

Any design with a diameter and service pressure equal to or less than the diameter and service pressure of a gas cylinder for which LBB and/or FCC testing has already been carried out does not require a repetition of the LBB or FCC test.

E.3 Leak before burst test (LBB test)

E.3.1 Flaw production procedure

The test shall be carried out on two gas cylinders. One flaw shall be machined on each gas cylinder to be tested. The flaw shall be machined longitudinally. It shall be located approximately at the mid-length of the cylindrical part of the gas cylinder, and at the point where the minimum wall thickness of this mid-section is recorded (based on four measurements equally spaced around the circumference).

The flaw length, l_o, shall be the overall length of the cut and shall be at least equal to 4a, where a is the calculated minimum thickness of the cylindrical shell (see Figure 1).

The cutter used to machine the flaw shall be approximately 12,5 mm thick, with an angle of 45° to 60° and a tip radius, r_c, of (0,25 ± 0,05) mm. The cutter diameter (= $2R_c$, where R_c is the radius of curvature of the end of the flaw as shown in Figure E.1) shall be 20 mm for gas cylinders with a nominal outside diameter, D, not greater than 140 mm and 30 mm for gas cylinders with D greater than 140 mm. A standard computer numerical controlled (CNC) cutter is recommended.

Larger cutter diameters, or other means of machining which do not affect the properties of the material, may be used when so required to achieve an appropriate flaw depth in thick-walled gas cylinders.

The depth of the flaw shall be equal to at least 60 % of the actual wall thickness, t, of the gas cylinder at the flaw location.

The cutter should be sharpened regularly to ensure that the tip radius meets the requirements.

Figure E.1 gives an overall view of the flaw and cutter geometries.

Dimensions in millimetres

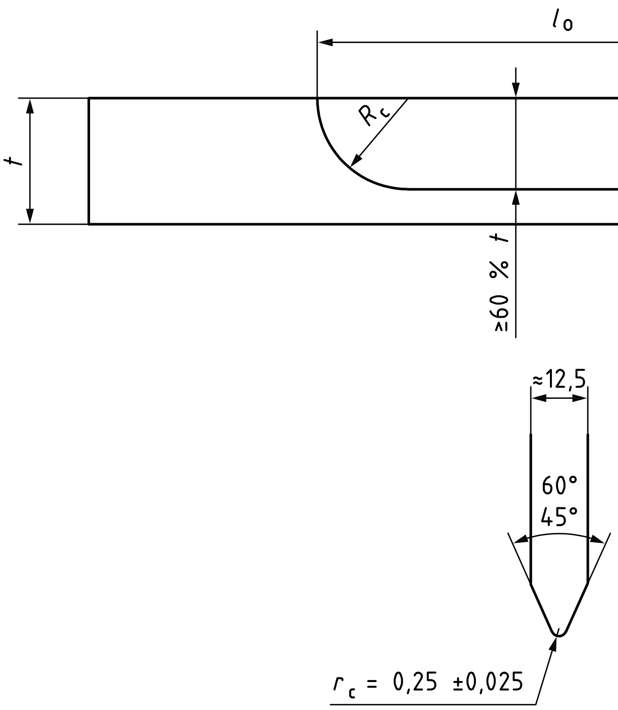


Figure E.1 — Overall view of the flaw and cutter geometries

E.3.2 Test procedure

E.3.2.1 General

Subject the flawed gas cylinders to either one of the two procedures described in E.3.2.2 and E.3.2.3.

E.3.2.2 Pressure-cycling test procedure

Subject each flawed gas cylinder to hydraulic pressure-cycling until failure, using the procedure described in 9.2.3, except that

— the upper cycling pressure, p_u, shall be at least 2/3 $p_h \times (t/a)$, and

— the cycling frequency shall not exceed 5 cycles per minute.

E.3.2.3 Constant-pressure test procedure

Hydraulically pressurize each flawed gas cylinder to failure using the test procedure described in 11.2.1, except for the duration of the test, which shall not be less than 1 min.

E.3.3 Acceptance criteria

E.3.3.1 Pressure-cycling test

a) The gas cylinder is deemed to have passed the test if the failure occurs by leakage, i.e. the overall length of the flaw after failure, as measured on the outer surface of the gas cylinder, does not exceed $1{,}1 \times l_o$.

b) If the criterion as per a) of this subclause is not met, then the corresponding type/batch, as applicable, shall be deemed to have failed the test.

c) If the number of cycles to failure falls well outside the range usually observed, typically when the crack propagation deviates from the radial direction, the test may be carried out again, but in this case two new gas cylinders shall be tested. If either of these new gas cylinders fails the test, then the corresponding type/batch, as applicable, shall be deemed to have failed the test.

E.3.3.2 Constant-pressure test

a) The gas cylinder is deemed to have passed the test when the following conditions are simultaneously fulfilled:

   — the failure shall occur by leakage, i.e. the overall length of the flaw after failure, as measured on the outer surface of the gas cylinder, shall not exceed $1{,}1 \times l_o$;

   — the failure pressure, p_f, shall be at least 2/3 $p_h \times (t/a)$.

b) If the failure pressure is less than 2/3 $p_h \times (t/a)$ and failure occurs by leakage, a new test may be carried out with a less deep flaw, the acceptance criteria remaining unchanged.

c) If the failure pressure exceeds 2/3 $p_h \times (t/a)$ and failure occurs by bursting, then a new test may be carried out with a deeper flaw, the acceptance criteria remaining unchanged.

d) If the criteria as per a) of this subclause are not met, then the corresponding type/batch, as applicable, shall be deemed to have failed the test.

E.3.4 Parameters to be monitored

E.3.4.1 Pressure-cycling test

Monitor the following parameters:

— actual flaw length;

— actual wall thickness;

— actual flaw depth;

— upper and lower cycling pressures;

— cycling rate;

- pressurizing medium used;
- temperature of the gas cylinder at the beginning and end of the test;
- number of cycles to failure;
- failure mode.

E.3.4.2 Constant-pressure test

Monitor the following parameters:

- actual flaw length;
- actual wall thickness;
- actual flaw depth;
- failure pressure;
- pressurizing medium used;
- failure mode.

E.4 Flawed gas cylinder cycle test (FCC test)

E.4.1 Flaw production procedure

The test shall be carried out on two gas cylinders. One flaw shall be machined on each gas cylinder to be tested. The flaw shall be machined longitudinally. It shall be located approximately at the mid-length of the cylindrical part of the gas cylinder, and at the point where the minimum wall thickness of this mid-section is recorded (based on four measurements equally spaced around the circumference).

The flaw length, l_o, shall be the overall length of the cut and shall be at least equal to $4a$, where a is the calculated minimum thickness of the cylindrical shell (see Figure 1).

The cutter used to machine the flaw shall be approximately 12,5 mm thick, with an angle of 45° to 60° and a tip radius, r_c, of (0,25 ± 0,05) mm. The cutter diameter (= $2R_c$, where R_c is the radius of curvature of the end of the flaw as shown in Figure E.1) shall be 20 mm for gas cylinders with a nominal outside diameter, D, not greater than 140 mm and 30 mm for gas cylinders with D greater than 140 mm. A standard computer numerical controlled (CNC) cutter is recommended.

The depth of the flaw shall be equal to 10 % of the actual wall thickness, t, of the gas cylinder at the flaw location.

When measuring the actual depth of the flaw after machining, a deviation not exceeding 0,10 mm from the depth specified is acceptable.

The cutter should be sharpened regularly to ensure that the tip radius meets the requirements.

E.4.2 Pressure-cycling procedure

Subject each flawed gas cylinder to hydraulic pressure-cycling until failure, using the procedure described in 9.2.3, except that

- the upper cycling pressure shall be at least equal to p_h, and
- the cycling frequency shall not exceed 5 cycles per minute.

E.4.3 Acceptance criteria

The test is deemed to have been passed if the mean value, for the two gas cylinders tested, of the number of cycles achieved without failure exceeds 2 000, with an absolute minimum of 1 500 for each gas cylinder.

E.4.4 Parameters to be monitored

Monitor the following parameters:

- actual flaw length;
- actual wall thickness;
- actual flaw depth;
- upper and lower cycling pressures;
- pressurizing medium used;
- temperature of the gas cylinder at the beginning and end of the test;
- number of cycles without failure;
- description of the failure.

E.5 Frequency of testing

E.5.1 Prototype testing

E.5.1.1 LBB test

This test shall be carried out for each new design (see 9.1 for the definition of a new design). Two gas cylinders selected from the batch of gas cylinders submitted to prototype testing shall be subjected to the LBB test.

E.5.1.2 FCC test

This test shall be carried out for each new design (see 9.1 for the definition of a new design). Two gas cylinders selected from the batch of gas cylinders submitted to prototype testing shall be subjected to the FCC test.

E.5.2 Production testing

In order to establish an initial database and to confirm the results obtained during prototype testing, enhanced testing is required when a manufacturer starts the production of gas cylinders using the provisions of this annex.

Only the LBB test is required for production testing.

One gas cylinder selected from the batch of gas cylinders submitted to production testing shall be subjected to the LBB test.

For each new design (see 9.1 for the definition of a new design), this test is required until a minimum of 10 batches of that same design have been successfully tested. In addition, this test is required until batches (of the same or of different designs) manufactured from a minimum of five different casts have been successfully tested.

The manufacturer shall keep a record of all such tests carried out, to be presented upon request.

E.6 Specific requirements for alloys with an elongation after fracture below 12 %

For such alloys, the manufacturer shall specify the chemistry and tolerances, the associated heat treatment, and the manufacturing route. As an example, the specification for alloy 2001 made by a hot-extrusion manufacturing route is given below.

Table E.1 gives the chemical composition of the aluminium alloy registered with the Aluminum Association.

Table E.1 — Chemical composition of aluminium alloy 2001

Type of alloy (AA registered designation)	**Marking code reference**	**Chemical composition** (% by mass)														
													Others			**Remarks**
			Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Zr	**Each**	**Total**	Al	
2001	2001	min.	—	—	5,2	0,15	0,20	—	—	—	—	—	—	—	Remainder	Pb: 0,003 max.
		max.	0,20	0,20	6,0	0,50	0,45	0,10	0,05	0,10	0,20	0,05	0,05	0,15		

As an example of what information is required with reference to 6.2, alloy 2001 shall be artificially aged at a temperature of (180 ± 5) °C for a minimum of 24 h, after a suitable solution heat treatment and quench. This information shall be made available to the Inspection Body.

With reference to 8.1, the gas cylinders shall be produced from cast or extruded billet.

With reference to 10.2.2, the elongation after fracture shall not be less than 9 % when the tensile test is carried out on a single test specimen taken from the gas cylinder wall. The tensile test may also be carried out on four test specimens distributed uniformly throughout the gas cylinder wall, in which case the results shall be as follows:

— no individual value may be less than 8 %;

— the average of the four measurements shall be at least 9 %.

Annex F
(informative)

Description and evaluation of manufacturing surface imperfections and conditions for rejection of seamless aluminium alloy gas cylinders at time of product acceptance

F.1 Introduction

Several types of imperfection can occur during the manufacture of a seamless aluminium alloy gas cylinder. Most of these are cosmetic features which do not affect the performance or life of the gas cylinder. In addition to meeting the requirements of this International Standard, the gas cylinder should be able to pass the periodic visual inspection and testing specified in ISO 10461.

The aim of this annex is to identify the manufacturing imperfections most commonly encountered and to suggest rejection criteria for use by the purchaser(s) and their representative(s) who might perform the visual inspection and acceptance testing of the gas cylinder. Only those imperfections which were specifically contracted (by purchase order or contract) should be evaluated for acceptance or rejection.

F.2 General

F.2.1 The inspection should be conducted in appropriate lighting on a product that is both clean and dry. If unclean, the surface may be cleaned under closely controlled conditions by a suitable method before inspection. The visual inspection should be conducted by eye, without magnification. Internal inspections may be augmented by a scope, dental mirror or another suitable device.

F.2.2 Small imperfections may be removed by local dressing, grinding, machining or another appropriate method when the purchaser has stipulated, when providing the purchase contract, that such imperfections are unacceptable. Great care should be taken to avoid introducing new, more serious, defects. After such a repair, gas cylinders should be re-examined and, if necessary, the wall thickness rechecked.

F.3 Manufacturing defects and imperfections

The most commonly found manufacturing defects and imperfections are listed, together with their definitions, in Table F.1. The table is written with requirements to allow the table to be utilized by the purchaser for contractual purposes. Proposed acceptance/rejection limits for repair or scrap are included in the table should the purchaser wish to contract such limits. If the table is used, then the suggested acceptance/rejection criteria in the “conditions and/or actions” column and the “repair or scrap column” apply. These rejection limits are subjective to the purchaser and the purchaser′s planned market and/or use of the product. They apply to all sizes and types of gas cylinders and service conditions. Nevertheless some purchaser specifications for some types of gas cylinders or some special service conditions may require more or less stringent criteria.

Table F.1 — Manufacturing defects and imperfections

Defect or imperfection	Description	Criteria for acceptance or rejection	Repair or scrap
Bulge	Visible swelling of the wall.	All cylinders with such a defect:	Scrap.
Dent (flat)	A visible depression in the wall that has neither penetrated the wall nor removed any metal and is greater in depth than 1 % of the outside diameter (see Figure F.1). (See also excessive grinding or machining.)	— When the depth of the dent exceeds 2 % of the external diameter of the cylinder — or when the diameter of the dent is less than 30× its depth — or when an external dent is visible on the internal surface: NOTE On small-diameter cylinders these general limits may have to be adjusted. Consideration of appearance also plays a part in the evaluation of dents, especially in the case of small cylinders.	Scrap.
Cut, gouge, metallic impression	An impression in the wall where metal has been removed or redistributed (due basically to the presence of foreign bodies on the mandrel or matrix during extrusion or drawing operations) to a depth of greater than 2 % of the diameter.	**Inside imperfection** — If more than 5 % of the wall thickness — or if remaining wall thickness under the defect is less than a' — or if with sharp notches — or when the length exceeds 5 × the minimum wall thickness: NOTE Consideration of appearance and location (in thicker parts with lower stresses) can be taken into account.	Scrap.
		Outside imperfection When the depth exceeds 5 % of the wall thickness or when the remaining wall thickness under the defect is less than a':	Scrap.
		Outside imperfection When the depth is less than 5 % of the wall thickness or when the remaining wall thickness under the defect is greater than a':	Repair if possible (see F.2.2).
Dent containing cut or gouge	A depression in the wall which contains a cut or gouge (see Figure F.2).	All cylinders with such an defect:	Scrap.
Excessive grinding or machining[a]	Local reduction of wall thickness by grinding or machining.	When the wall thickness is reduced to below the minimum design thickness:	Scrap.
		When it results in the formation of a dent:	See "dent" above.

Table F.1 (*continued*)

Defect or imperfection	Description	Criteria for acceptance or rejection	Repair or scrap
Ridge or rib[a]	A longitudinal raised surface with sharp corners (see Figure F.3).	**Inside imperfection** If the height exceeds 5 % of the wall thickness:	Scrap.
		Outside imperfection Where the height exceeds 5 % of the wall thickness:	Repair if possible (see F.2.2).
Groove	A deep longitudinal notch (see Figure F.4).	**Inside imperfection** If the depth exceeds 5 % of the wall thickness or if the remaining wall thickness under the defect is less than a':	Scrap.
		Outside imperfection If the depth exceeds 5 % of the wall thickness or if the remaining wall thickness under the defect is less than a':	Scrap.
		Outside imperfection If the depth is less than 5 % of the wall thickness or if the remaining wall thickness under the defect is greater than a':	Repair if possible (see F.2.2).
Lamination[a]	Layering of the material within the cylinder wall and sometimes appearing as a discontinuity, crack, lap or bulge at the surface (see Figure F.5).	**Inside imperfection** All cylinders with such an imperfection:	Scrap.
		Outside imperfection All cylinders with such an imperfection:	Repair if possible (see F.2.2).
Blister[a]	Small bulge on the wall containing a continuous layer of inclusions	**Inside imperfection** All cylinders with such an imperfection where blister is greater than 2 mm in diameter:	Scrap.
		Outside imperfection All cylinders with such an imperfection where blister is deeper than 5 % of wall thickness:	Repair if possible (see F.2.2). (Not necessary to repair if clearly insignificant to cylinder performance.)
Crack	A split or separation in the metal, forming a line.	All cylinders with such an imperfection:	Scrap.
Neck cracks	Appear as lines which run vertically down the thread and across the thread faces (they should not be confused with tap marks or thread machining marks) (see Figure F.6).	All cylinders with such an imperfection:	Scrap.

Table F.1 (*continued*)

Defect or imperfection	Description	Criteria for acceptance or rejection	Repair or scrap
Shoulder folds	Folding with peaks and troughs, situated in the internal shoulder area, which propagates into the threaded area of the shoulder (see Figure F.7).	When folds are visible as a line running into the threaded portion and across more than two full threads: (Folds which extend beyond the machined area and are clearly visible as open depressions where no oxides have been trapped in the metal are acceptable, provided the peaks are smooth and the root of the depression is rounded.) See 11.5 for other criteria for scrapping and repair.	Repair or scrap. If the folding has been removed by machining and the wall thickness is satisfactory, then the imperfection is acceptable. After repairing by machining, the whole area shall be re-inspected carefully and the wall thickness verified.
Shoulder cracks	Can start in the internal shoulder area and propagate into the cylindrical machined or threaded area of the shoulder (Figure F.8 shows where shoulder cracks start and how they propagate).	If cracks are visible along their whole length or if wall thickness is unsatisfactory:	Scrap.
Internal threads damaged or out of tolerance	Threads damaged, with dents, cuts or burrs, or out of tolerance.	If the design permits:	Repair by re-tapping and re-checking the threads with the appropriate thread gauge followed by careful visual re-examination. Re-tapped threads must meet at least the minimum design requirements.
		If not repairable:	Scrap.
Pitting	Small holes in metal due to chemical or water attack.	**Inside imperfection** If the diameter of the largest pit is greater than 2 mm or if the depth of any pit is greater than 2 % of the wall thickness:	Scrap.
		Outside imperfection All cylinders with such defects of depth less than 2 % of the wall thickness:	Repair if possible (see F.2.2).
Non-conformity with design drawing[a]	Does not conform to the design drawing (concerning e.g. neck or bottom shape and dimensions, out of straightness, stability, lack of thickness).	All cylinders presenting such an imperfection:	Repair if possible (see F.2.2) or, if this is unacceptable to the purchaser, scrap.
Neck ring not secure	Neck ring turns under application of low torque or pulls off under low axial load (see 7.6).	All cylinders presenting such an imperfection:	Repair if possible (see F.2.2) or scrap.
Arc or torch burns	Partial burning of the cylinder metal, the addition of weld metal or the removal of metal by scarfing or cratering.	All cylinders presenting such an imperfection:	Scrap.

NOTE Lubrication marks which arise during the extrusion process, and which can be inside or outside, are subject to a standard agreed between manufacturer and purchaser or purchaser's designated Inspection Body. Such marks outside the agreed limits can cause the gas cylinder to be scrapped.

[a] This inside imperfection, when detected before necking, may be repaired, if possible, prior to closure.

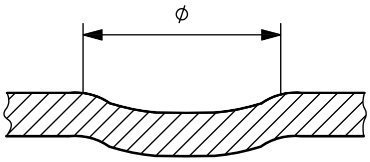


Figure F.1 — Dent

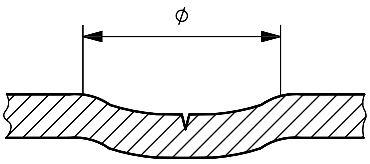


Figure F.2 — Dent containing cut or gouge

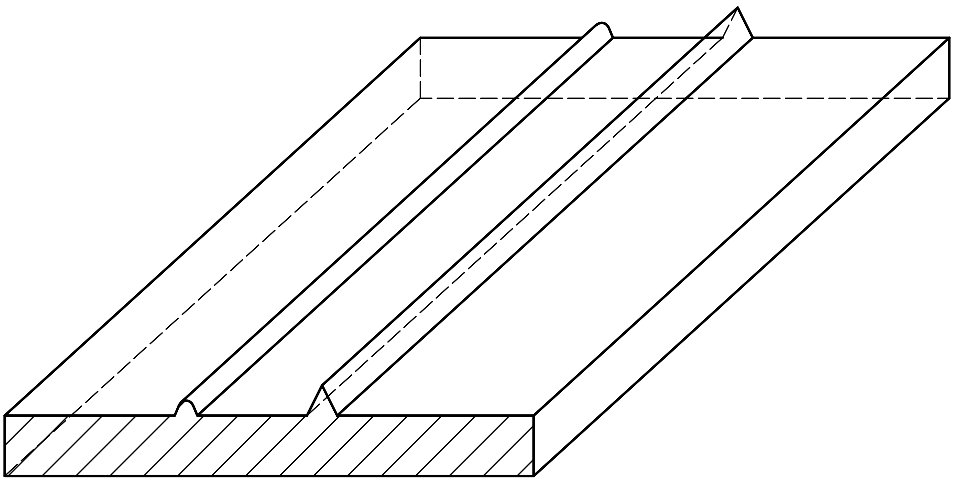


Figure F.3 — Ridges or ribs

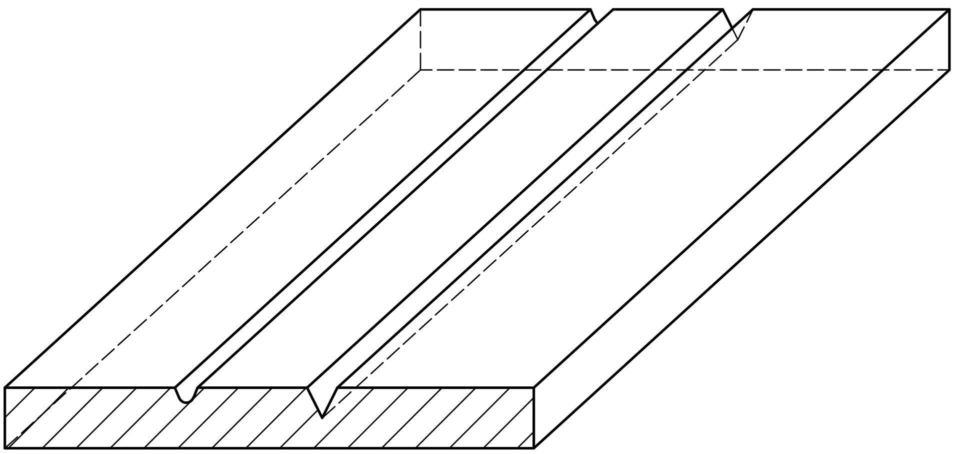


Figure F.4 — Grooves

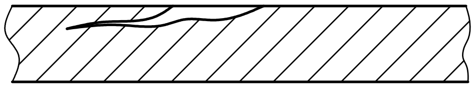
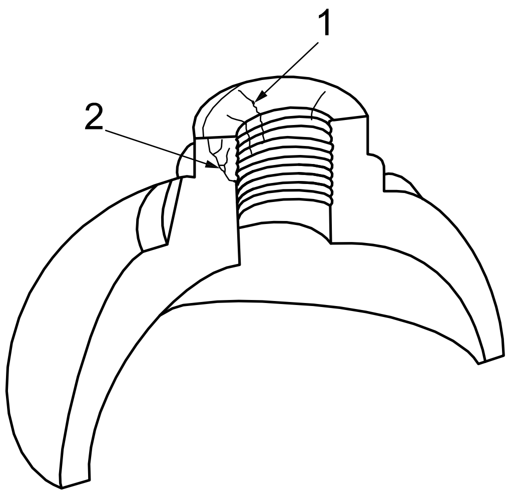


Figure F.5 — Lamination

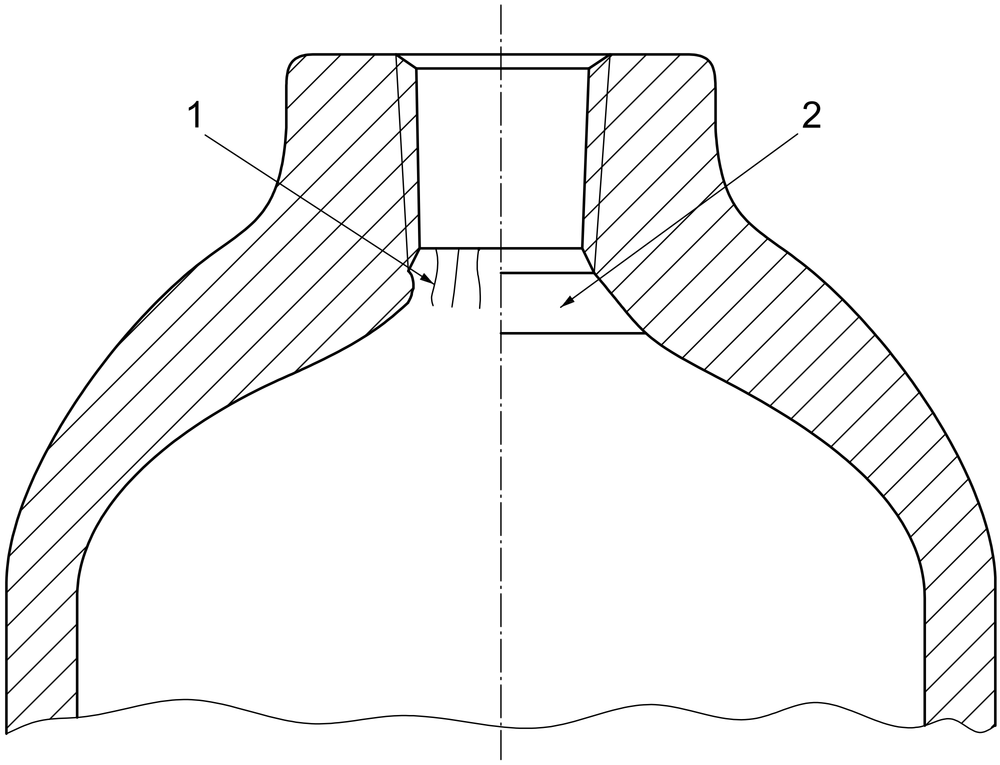


Key

1 neck crack

2 neck crack which has propagated

Figure F.6 — Neck cracks

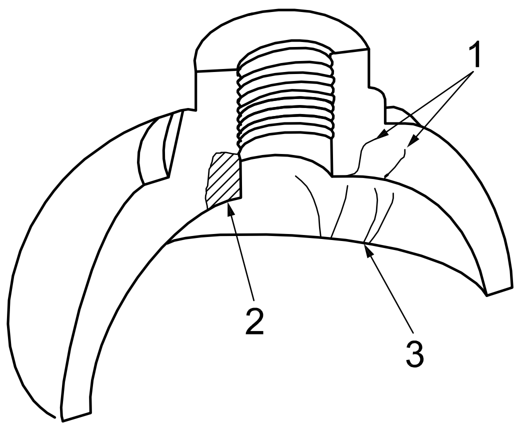


Key

1 folds or cracks

2 after machining

Figure F.7 — Shoulder folds and cracks



Key

1 shoulder cracks

2 shoulder crack which has propagated

3 folds

Figure F.8 — Shoulder cracks

Annex G
(normative)

Batch size

The production gas cylinder batch size shall be determined in accordance with Table G.1. The batch sizes given do not include the gas cylinders needed for sampling and testing, which may be added to the batch.

Table G.1 — Batch size

Water capacity (litres)	**Water capacity times test pressure** (bar·litres)	**Batch size**
> 1	Any value	200
Any capacity up to 150	> 300	200
≤ 1	> 150 but ≤ 300	500
≤ 1	≤ 150	1 000

Annex H
(normative)

Specific provisions for acetylene cylinder shells

H.1 Shells of acetylene cylinders shall be designed and manufactured following all the requirements of this International Standard, in particular the design formulae given in 7.2, and the guaranteed mechanical properties resulting from the shell manufacturing process shall be used.

H.2 In addition, the manufacturer of the gas cylinder shell shall provide information on the maximum temperature the shell may be subjected to, so that the manufacturer and filler of the porous material can decide whether the shell is suitable for the porous material. The new minimum mechanical properties resulting from the application of heat shall be used to verify that the wall thickness of the shell is sufficient, using the simple mean-diameter formula and a safety factor of 2,5 for R_{mg}. For every new type of shell, the influence of the temperature and time on the mechanical properties of the aluminium alloy shall be checked on a shell exposed to the maximum temperature expected during massing, for the maximum expected time. Three tensile specimens, taken from the exposed shell, shall be used for testing. The exposed shell shall also be checked to ensure that the heat exposure does not make the alloy sensitive to intercrystalline corrosion or stress corrosion cracking. Tests in accordance with Annexes A, B, and E shall be carried out on specimens from gas cylinder shells exposed to the extreme temperature for the maximum time. These tests on a shell manufactured from a specific material are material tests and are not required for every type. When alloys such as 5283 are used to manufacture the shell, it shall be ensured that the design is based upon fully annealed mechanical properties (e.g. O-temper).

EXAMPLE

AA shell $R_{ma} > 330$ MPa, $R_{eg} > 280$ MPa, $p_h = 60$ bar (6 MPa);

OD = 142 mm, $a = 8{,}0$ mm;

massing conditions: 250 °C max. for 72 h max.

H.3 Testing shall be carried out to verify that the design requirements specified in 7.2 have been met.

Bibliography

[1] ISO 209, *Aluminium and aluminium alloys — Chemical composition*

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

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

[4] ISO 11363-1, *Gas cylinders — 17E and 25E taper threads for connection of valves to gas cylinders — Part 1: Specifications*

[5] ISO 11363-2, *Gas cylinders — 17E and 25E taper threads for connection of valves to gas cylinders — Part 2: Inspection gauges*

[6] ASTM E1221-06, *Standard Test Method for Determining Plane-Strain Crack-Arrest Fracture Toughness, K_{Ia}, of Ferritic Steels* (see in particular Subclause 9.2.1)

[7] ASTM E399-09, *Standard Test Method for Linear-Elastic Plane-Strain Fracture Toughness, K_{Ic}, of Metallic Materials* (see in particular Subclause A.5.5.5)

[8] TADA, H., PARIS, P. and IRWIN, G. *The Stress Analysis of Cracks Handbook*, 2nd Edition, 1985, p. 236, Paris Production Inc., St. Louis, Missouri, 63105, USA

[9] *UN Recommendations on the Transport of Dangerous Goods — Model Regulations*

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