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Gas cylinders — Refillable welded aluminium-alloy cylinders — Design, construction and testing

*Bouteilles à gaz — Bouteilles rechargeables soudées en alliage
d'aluminium — Conception, construction et essais*



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Foreword

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

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 20703 was prepared by Technical Committee ISO/TC 58, *Gas cylinders*, Subcommittee SC 3, *Cylinder design*.

This International Standard has been prepared to address the general requirements in Section 6.2.1 of the UN model regulations for the transportation of dangerous goods ST/SG/AC.10/1/Rev.13. It is intended to be used under a variety of regulatory regimes but has been written so that it is suitable for use with the conformity assessment system in paragraph 6.2.2.5 of the above mentioned model regulations.

Introduction

The purpose of this International Standard is to provide a specification for the design, manufacture, inspection and approval of refillable, transportable, welded aluminium-alloy gas cylinders. The specifications given are based on knowledge of, and experience with, materials, design requirements, manufacturing processes and control during manufacture of cylinders in common use in the countries of the participating members.

Gas cylinders — Refillable welded aluminium-alloy 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 manufacture of refillable, transportable, welded aluminium-alloy gas cylinders of water capacities from 0,5 l up to and including 150 l, and of a test pressure not greater than 60 bar (6 MPa) for compressed, liquefied and dissolved gases.

This International Standard includes requirements for spherical receptacles and cylinders made from seamless bodies with welded non-pressure-bearing attachments such as shrouds and foot-rings.

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 2107, *Aluminium and aluminium alloys — Wrought products — Temper designations*

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

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

ISO 7438, *Metallic materials — Bend test*

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

ISO 9606-2, *Qualification test of welders — Fusion welding — Part 2: Aluminium and aluminium alloys*

ISO 10042:2005, *Welding — Arc-welded joints in aluminium and its alloys — Quality levels for imperfections*

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

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

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

ISO 13769, *Gas cylinders — Stamp marking*

ISO 15614-2:2005, *Specification and qualification of welding procedures for metallic materials — Welding procedure test — Part 2: Arc welding of aluminium and its alloys*

3 Terms, definitions and symbols

3.1 Terms and definitions

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

3.1.1

yield stress

value corresponding to the 0,2 % proof stress (non proportional elongation), $R_{p0,2}$

3.1.2

solution heat treatment

thermal treatment which consists of heating the products to a suitable temperature, holding at that temperature long enough to allow constituents to enter into solid solution, and cooling rapidly enough to hold the constituents in solution

3.1.3

quenching

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

3.1.4

artificial ageing

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

3.1.5

batch

quantity of up to 250 cylinders, plus cylinders for destructive testing, of the same nominal diameter, thickness and design, made successively from the same cast and subjected to the same heat treatment for the same period of time; the lengths of the cylinders in the heat treatment batch may vary by up to $\pm 12\%$

3.1.6

design stress factor

F
ratio of equivalent wall stress at test pressure (p_h) to guaranteed minimum yield stress (R_e)

3.1.7

non-destructive examination

examination or test that does not materially or adversely affect the item being examined

3.2 Symbols

- A percentage elongation, determined by the tensile test 7.2.3
- a calculated minimum thickness, in millimetres, of the cylindrical or spherical shell
- a' guaranteed minimum thickness, in millimetres, of the cylindrical or spherical shell
- b guaranteed minimum thickness, in millimetres, at the centre of a convex base
- D_o nominal outside diameter, in millimetres, of the cylinder, spherical cylinder or domed end (see Figure 2)
- D_i nominal inside diameter, in millimetres, of the cylinder, spherical cylinder or domed end (see Figure 2)
- d diameter of former, in millimetres (see Figure 4)
- F design stress factor (variable) (see 3.1.6)

h_i	internal height, in millimetres, of semi-ellipsoidal or torispherical domed end (convex head or base end) (see Figure 2)
h_e	variable used in the determination of shape factor, K (see 5.3.1)
h_o	external height, in millimetres, of a semi-ellipsoidal or torispherical domed end (convex head or base end) (see Figure 2)
K	shape factor for a semi-ellipsoidal or torispherical domed end, obtained according to the values h_e/D_o and a/D_o , with interpolation where necessary (see Figure 1)
L_o	original gauge length, in millimetres, according to ISO 6892
n	ratio of the diameter of the bend test former to actual thickness of test piece (t)
p_b	measured burst pressure, in bar ¹⁾ above atmospheric pressure
p_h	hydraulic test pressure, in bar ¹⁾ above atmospheric pressure
p_{lc}	lower cyclic pressure, in bar ¹⁾ above atmospheric pressure
p_y	observed yield pressure which produces a permanent volumetric expansion of 0,2 %, in bar ¹⁾ above atmospheric pressure
R_e	minimum guaranteed value of yield stress (see 3.1.1), in megapascals, for the finished cylinder
R_{ea}	actual value of yield stress, in megapascals, determined by the tensile test 7.2.3.
R_g	minimum guaranteed value of tensile strength, in megapascals, for the finished cylinder
R_m	actual value of tensile strength, in megapascals, determined by the tensile test 7.2.3
r_i	internal knuckle radius, in millimetres, of torispherical end [see Figure 2c)]
r'_i	internal radius, in millimetres, of dishing of torispherical end [see Figure 2c)]
r_a	external knuckle radius, in millimetres, of torispherical end [see Figure 2c)]
r'_o	external radius, in millimetres, of dishing of torispherical end [see Figure 2c)]
s_f	straight flange length, in millimetres, for semi-ellipsoidal and torispherical domed ends [see Figure 2b) and 2c)]
S_o	original cross-sectional area of tensile test piece, in square millimetres, according to ISO 6892
t	actual thickness of test specimen, in millimetres
t_e	calculated minimum thickness, in millimetres, of a domed end
w	width, in millimetres, of tensile test piece
V_{exp}	volumetric expansion attained at burst, expressed as a percentage of the initial volume (see 7.3)
Z	stress reduction factor (see 5.2.1)

1) 1 bar = 10⁵ Pa = 10⁵ N/m².

4 Materials

4.1 General provisions

4.1.1 Aluminium alloys may be used to produce gas cylinders provided that they satisfy the requirements of the corrosion resistance tests defined in Annex A, and meet all other requirements of this International Standard.

4.1.2 Examples of the alloys most commonly used for the fabrication of gas cylinders are given in Table 1.

4.1.3 After the completion of all welding (including that of the attachments) and before the hydraulic test, each cylinder shall be heat treated if required to meet the design criteria.

4.2 Heat treatment

4.2.1 General

Any welding on the pressure-bearing part shall take place before any final heat treatment (see **6.2**).

4.2.2 Heat-treatable alloys

The manufacturer shall specify on the new design type testing documentation, where required, the solution heat treatment and artificial ageing temperatures and the times for which the cylinders have been held at those temperatures. The medium used for quenching after solution heat treatment shall be identified.

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

However, the stabilizing treatment is not necessary for a cylinder of which the wall thickness in **5.2** is calculated with the minimum guaranteed yield stress value of the O-tempered alloy (or the alloy annealed for complete re-crystallization before forming of cylinder, as defined in ISO 2107).

If the cylinder is intended for dissolved-gas service it shall only be used in the fully annealed condition, i.e. the minimum guaranteed properties used for the material shall consider the heat treatment to be applied, e.g. during the massing operation.

4.2.3 Non-heat-treatable alloys

The manufacturer shall specify on the new design type testing documentation, where required, 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 treatment shall be carried out and the temperature, and time at temperature, shall be identified by the manufacturer.

4.2.4 Control of specified heat treatment

During the heat treatment, the manufacturer shall comply with the specified temperatures and durations, within the following ranges:

a) Temperatures

Solution temperature: maximum range 20 °C

Artificial ageing temperature: maximum range 20 °C

Stabilizing temperature: maximum range 20 °C

b) Durations

Time cylinders actually spend at temperature during treatments:

All treatments: maximum range 20 %

4.3 Gas/material compatibility

Gas/material compatibility shall be verified as specified in ISO 11114-1.

5 Design

5.1 General provisions

5.1.1 The calculation of the wall thickness of the pressure-bearing parts shall be related to the yield stress (R_e) of the material to ensure elastic behaviour.

5.1.2 For calculation purposes, the value of the yield stress (R_e) is limited to a maximum of $0,9 R_g$ for aluminium alloys.

5.1.3 The internal pressure upon which the calculation of wall thickness is based shall be hydraulic test pressure (p_h).

5.1.4 For dissolved gases, the manufacturing process of the porous mass can modify the characteristics of the aluminium alloy used. This shall be considered when designing the shell.

5.1.5 Wherever any exposure to heat is necessary (e.g. for dissolved acetylene, where the manufacturing process of the porous mass can modify the characteristics of the aluminium alloy used) this shall be considered when designing the shell, i.e. the mechanical properties guaranteed by the shell manufacturer shall be those resulting from any heating prior to final use.

Table 1 — Chemical composition of aluminium alloys

Type of alloy AA ^a registered designation	Type ^{b, c}	Chemical composition — weight %													Aluminium		
		Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Pb	Bi	Others					
												Each	Total				
5052	A	min.	—	—	—	2,2	0,15	—	—	—	—	—	—	—	—	—	Remainder
		max.	0,25	0,40	0,10	0,10	2,8	0,35	0,10	—	—	—	—	0,05	0,15	—	Remainder
5154	A	min.	—	—	—	3,1	0,15	—	—	—	—	—	—	—	—	—	Remainder
		max.	0,25	0,40	0,10	0,10	3,9	0,35	0,20	0,20	—	—	—	0,05	0,15	—	Remainder
5083A	D	min.	—	—	0,40	4,0	0,05	—	—	—	—	—	—	—	—	—	Remainder
		max.	0,40	0,40	0,10	1,0	4,9	0,25	0,25	0,15	—	—	—	0,05	0,15	—	Remainder
6061A	D	min.	0,40	—	—	0,8	0,04	—	—	—	—	—	—	—	—	—	Remainder
		max.	0,8	0,7	0,40	0,15	1,2	0,35	0,25	0,15	0,0030	0,0030	0,0030	0,05	0,15	—	Remainder
6063	C	min.	0,2	—	—	0,4	—	—	—	—	—	—	—	—	—	—	Remainder
		max.	0,7	0,5	0,1	0,3	0,9	0,1	0,2	0,2	0,0030	—	—	0,05	0,15	—	Remainder
6082	D	min.	0,7	—	—	0,60	—	—	—	—	—	—	—	—	—	—	Remainder
		max.	1,3	0,50	0,10	1,0	1,2	0,25	0,20	0,10	0,0030	0,0030	0,0030	0,05	0,15	—	Remainder
6082	B	min.	1,2	—	—	1,0	—	—	—	—	—	—	—	—	—	—	Remainder
		max.	1,6	0,5	0,1	1,0	1,4	0,1	0,2	0,2	0,0030	0,0030	0,0030	0,05	0,15	—	Remainder

^a AA is the Aluminium Association Inc., 900 19th Street N.W., Washington D.C., 20006-2168, USA.

^b Type A and Type B may be used for the body and Type C for the non pressure bearing part.

^c Type D may be used for the body and the non-pressure-bearing part.

5.2 Calculation of wall thickness

5.2.1 Wall thickness of cylindrical shell

The guaranteed minimum thickness of the cylindrical shell (a') shall not be less than the thickness calculated using the equation

$$a = \frac{D_o}{2} \left(1 - \sqrt{\frac{10 FZ R_e - \sqrt{3} \cdot p_h}{10 FZ R_e}} \right)$$

The value of F is the lesser of $\frac{0,65}{(R_e / R_g)}$ and 0,85; R_e/R_g shall be limited to 0,9.

The value of Z is dependent on the amount of non-destructive examination (NDE) and the type of cylinder; it shall be as specified in Table 2. Z shall apply to external welds such as welding of shrouds and foot-rings.

The manufacturer may choose between 100 % NDE of welds or spot checks defined as follows:

- for circumferential welds (including of bung or boss welds), 25 mm on each side of the weld overlap shall be examined;
- for longitudinal welds, 100 mm beyond the intersection of the circumferential/longitudinal weld and 25 mm on each side of the circumferential weld shall be examined.

Table 2 — Stress reduction factor Z

Cylinder type		Stress reduction factor Z
Without longitudinal welds	100 % of welds NDE tested	1,00
	Welds spot checked	0,95
With longitudinal welds	100 % of welds NDE tested	0,95
	Welds spot checked	0,90

The calculated minimum thickness shall also satisfy the equation

$$a \geq \frac{D_o}{200} + 1,5 \text{ mm.}$$

When choosing the guaranteed value of the wall thickness of the cylindrical shell (a'), the manufacturer shall take into account all the test requirements for new design type and production testing, particularly the burst test requirements of 7.3.2.2.

The burst ratio (p_b/p_h) shall be determined by test and shall be $> 2,0$.

5.2.2 Wall thickness of spherical cylinder

The thickness of the wall shall not be less than the values given by the following equations:

$$a = (p_h D_i) / (40 F Z R_e - 4,5 p_h)$$

$$a = (p_h D_o) / (40 F Z R_e - 2,5 p_h)$$

$$a = 2,48 \sqrt{D_i / R_g}$$

The values of F and Z shall be as defined in 5.2.1.

5.3 Design of convex ends (heads and bases)

5.3.1 Thickness of domed ends

For cylinders made with a seamless body, the method of construction of ISO 7866:1999, 7.3.1, 7.3.2 and 7.3.3 shall be used. For cylinders made with a welded body, the minimum thickness of a hemispherical domed end shall be equal to the minimum thickness of the cylindrical shell a .

The minimum thickness of a semi-ellipsoidal or torispherical domed end shall be the greater of

- the thickness of the cylindrical wall, and
- the value of t_e calculated from the equation

$$t_e = aK$$

where K shall be as determined from Figure 1.

For a semi-ellipsoidal end, $h_e = h_o$.

For a torispherical end, h_e is the lesser of h_o , $\frac{D_o^2}{4r_o'}$ and $\sqrt{\left(\frac{D_o r_o}{2}\right)}$.

NOTE The external height of a torispherical domed end (h_o), can be determined from

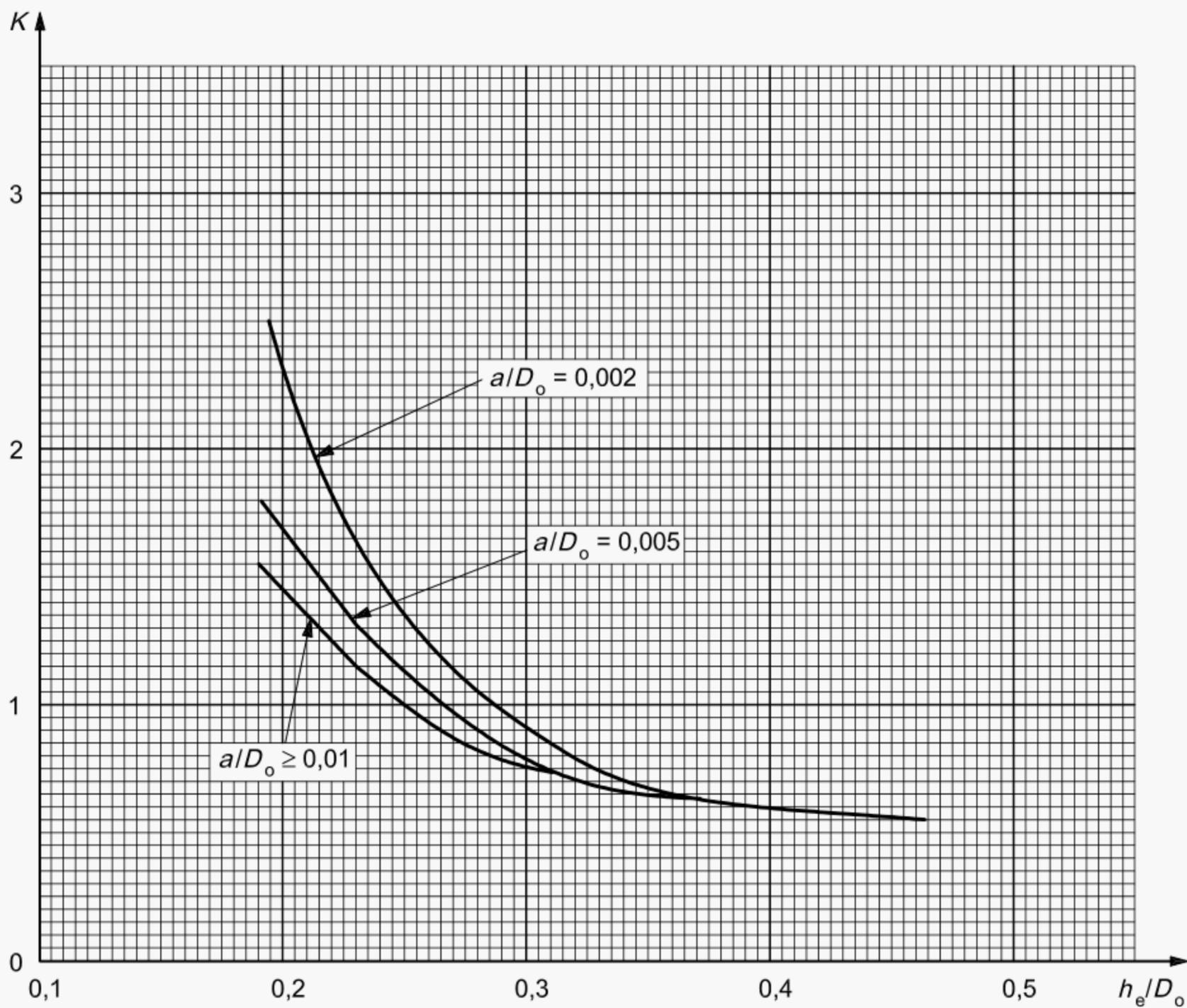
$$h_o = r_o' - \sqrt{\left\{ \left(r_o' - \frac{D_o}{2} \right) \times \left(r_o' + \frac{D_o}{2} - 2r_o \right) \right\}}$$

The wall thickness of the base shall not exceed 1,15 times the guaranteed minimum design thickness of the base (b). The external surface of the base of the selected cylinders may be machined if necessary.

5.3.2 Limitations of shape (see Figure 2)

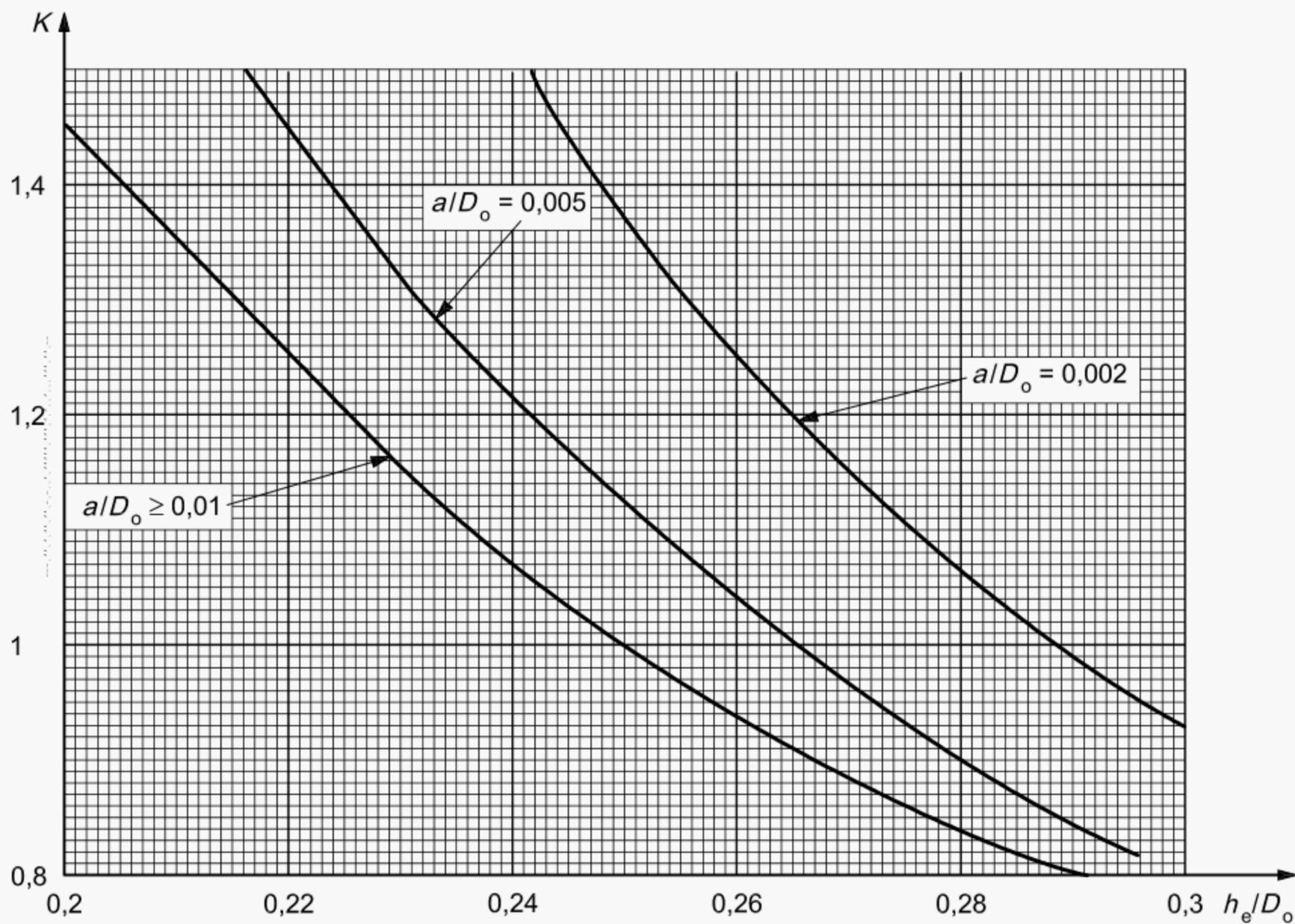
The shape of the ends shall be subject to the following limitations.

- For a torispherical end, r_i' shall be not greater than D_o .
- For a torispherical end, r_i shall be not less than $0,1D_i$ and not less than three times the actual thickness of the end as manufactured.
- For a semi-ellipsoidal end, the ratio h_o/D_o shall be not less than 0,192.
- For a semi-ellipsoidal end and a torispherical end, s_f shall be not less than $0,3\sqrt{(D_o t_e)}$.



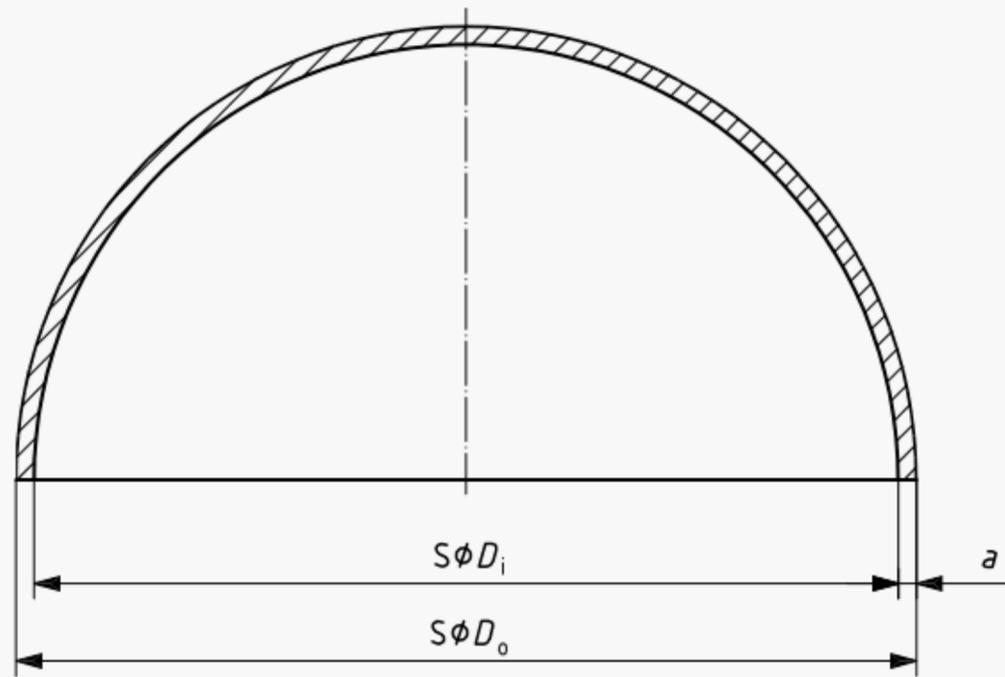
a) Shape factor K

Figure 1 — Shape factor K plotted against h_e/D_o

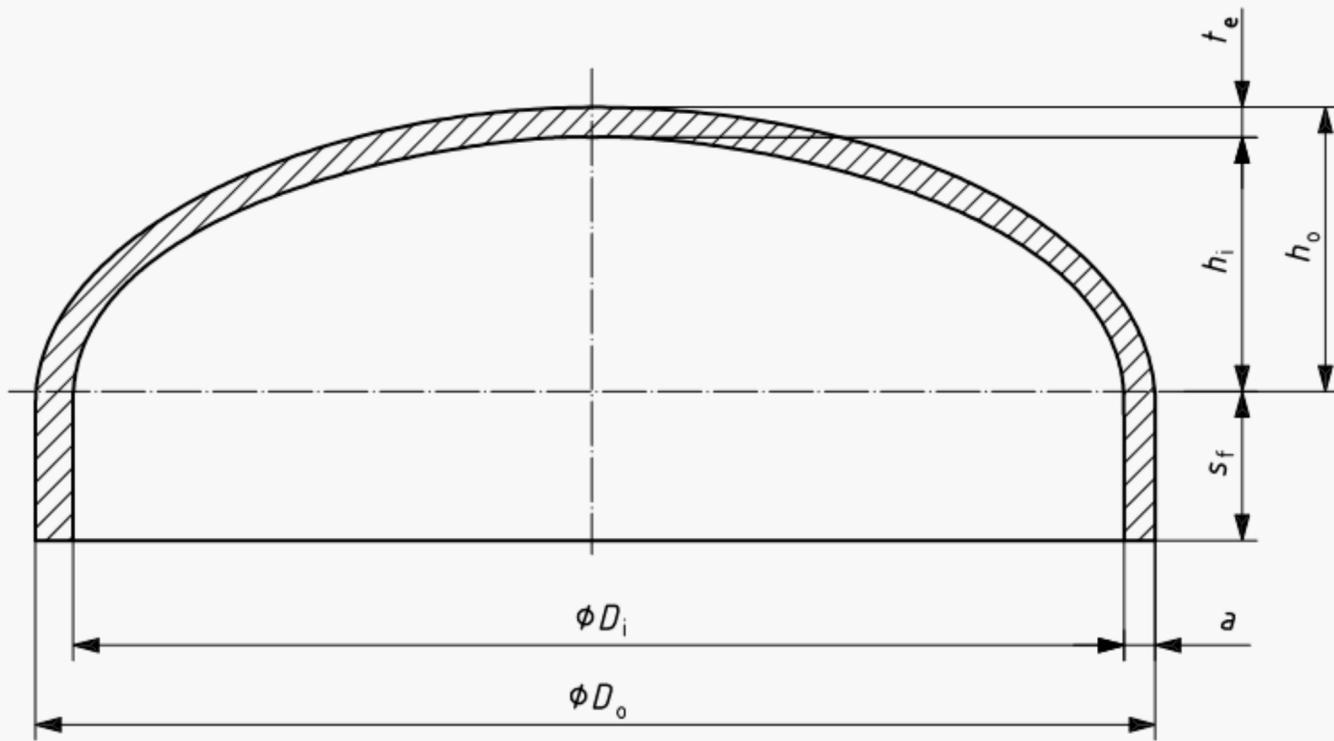


b) Shape factor K [enlargement of a]

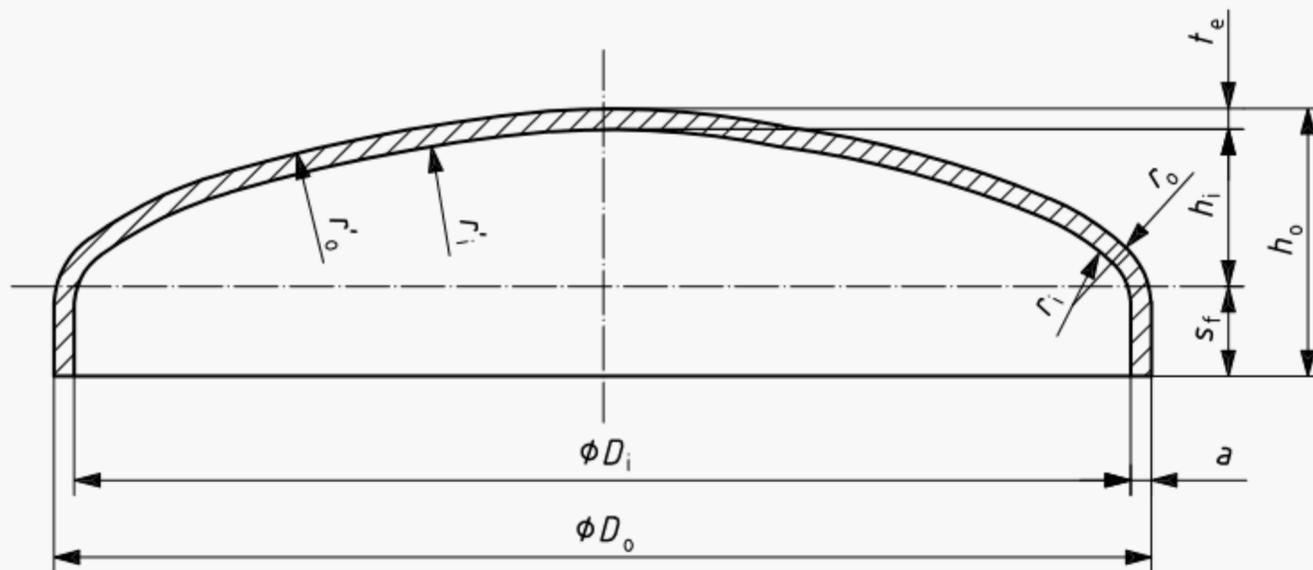
Figure 1 (continued)



a) Hemispherical



b) Semi-ellipsoidal



c) Torispherical

Figure 2 — Domed ends

5.4 Neck design

The external diameter and thickness of the formed neck end of the cylinder shall be designed for the torque applied in fitting the valve to the cylinder. The torque may vary according to the diameter of thread, the form, and the sealant used in the fitting of the valve. The torques specified in ISO 13341 shall not be exceeded, since this could result in permanent damage to the cylinder. Where the cylinder manufacturer specifies a lower maximum torque than that indicated in ISO 13341 (but within the range of ISO 13341), the manufacturer shall notify any such requirements to the purchaser of aluminium-alloy cylinders.

5.5 Foot-rings

A foot-ring, if provided, shall be sufficiently strong and made of material compatible with that of the cylinder. In addition, the shape should preferably be cylindrical and shall give the cylinder sufficient stability. The foot-ring shall be secured to the cylinder, e.g. by welding. Water traps shall be sealed.

5.6 Neck-rings

When a neck-ring is provided, it shall be of material compatible with that of the cylinder, and shall be securely attached. The manufacturer shall ensure that the axial load required to remove the neck-ring is greater than 10 times the weight of the empty cylinder and not less than 1 000 N, and that the minimum torque to turn the neck-ring is greater than 100 N·m. The valve protection requirements specified in ISO 11117 apply.

5.7 Shroud

When a shroud for valve protection is provided, it shall be secured to the cylinder, e.g. by welding. Design consideration shall be given to avoid water traps in contact with the pressure-bearing part.

5.8 Design drawing

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

6 Construction and workmanship

6.1 Seamless bodies

For cylinders made with a seamless body, the method of construction of ISO 7866 shall be used.

6.2 Welding

Prior to welding, the components shall be prepared and inspected according to approved procedures. These procedures shall be laid down in a welding procedure document to be supplied for new design type testing. Welding shall be according to the approved welding procedures, which shall be in accordance with ISO 15614-2. Test pieces and acceptance criteria shall be in accordance with ISO 15614-2:2005, Clause 7. The number of test pieces shall be in accordance with ISO 15614-2:2005, Table 1.

If welding is carried out manually, the welders shall be approved in accordance with ISO 9606-2.

Before the cylinders are closed, longitudinal welds shall be visually examined from both sides.

Parts such as neck-rings, foot-rings, shrouds, handles or bosses may be attached to the cylinder by welding, provided that the cylinder is not adversely affected by welding and any welding is performed prior to any heat treatment.

Neck-rings may be attached to the cylinder by welding, screwing, shrinking, etc.

The longitudinal joint, of which there shall be no more than one, shall be butt-welded and shall have 100 % penetration.

6.3 Non-destructive examination of welds

6.3.1 NDE shall be carried out in accordance with the design basis selected in **5.2** (i.e. 100 % NDE or spot checks). The examination shall be performed by an X-ray inspection. The X-ray apparatus shall have a minimum sensitivity capable of revealing defects having a size equal to 4 % of the combined thickness of the weld and the backing material (if used).

6.3.2 The circumferential and longitudinal welds and the bung or boss butt-welds shall be radiographed in order to establish satisfactory machine settings. This shall be carried out on the introduction, or reintroduction after a period exceeding three days, of a new design of cylinder (see Annex A) to a production line, for the first cylinder welded, or more at the discretion of the inspector. The radiographs shall be assessed in accordance with ISO 10042 and bulk production shall not commence unless they are found to be satisfactory.

6.3.3 Thereafter during production of that design of cylinder, in order to demonstrate that satisfactory welds are being produced consistently, one cylinder shall be selected at random at the beginning and end of each working shift's production or at intervals not exceeding 12 h, whichever is the shorter, and radiographed as above.

6.3.4 Defect acceptance criteria shall be in accordance with ISO 10042:2005 quality level C. If the radiographs show no unacceptable defects, the whole of the production of the relevant working shift shall be accepted subject to further tests as specified in **B.2**.

6.3.5 Should any of the radiographs show an unacceptable defect, production shall be stopped and the whole of the relevant shift's production shall be quarantined until it is demonstrated that the cylinders are satisfactory, either by radiography or by other appropriate means approved by the inspector.

6.3.6 Production shall not be restarted until the cause of the defect has been established and rectified, and the starting up test procedure, as specified above, has been repeated.

6.3.7 Any weld repairs shall be according to an approved welding procedure. All weld repairs should be radiographed and rewelded. After rewelding and, where necessary, re-radiography, all cylinders shall be re-heat treated as part of a new batch or production run in accordance with **B.3**, and shall be retested accordingly. Acceptance criteria shall be in accordance with Annex C.

6.4 Surface defects

The internal and external surfaces of the finished cylinder shall be free from defects that would adversely affect the safe working of the cylinder. Such defects shall be removed by local dressing in a manner that does not introduce stress risers. The wall thickness of any dressed area shall not be less than the minimum thickness specified.

6.5 Neck threads

The internal neck threads shall conform to a recognized standard agreed between the parties to permit the use of a corresponding valve, thus minimizing neck stresses following the valve torquing operation. Internal neck threads shall be checked using gauges corresponding to the agreed neck thread, or by an alternative method agreed between the parties.

EXAMPLE 1 Where the neck thread is specified to be in accordance with ISO 10920:1997, the corresponding gauges are specified in ISO 11191:1997.

EXAMPLE 2 Where the neck thread is specified to be in accordance with ISO 11116-1:1999, the corresponding gauges are specified in ISO 11116-2:1999.

Particular care shall be taken to ensure that neck threads are accurately cut, are of full form and are free from any sharp profiles, e.g. burrs.

6.6 Out-of-roundness

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

6.7 Straightness

The maximum deviation of the cylindrical part of the shell from a straight line shall not exceed 10 mm per metre length.

6.8 Eccentricity

When measured on the same cross-section of a cylinder, the minimum and maximum wall thicknesses of the shell shall not deviate by more than 10 % from the average of these two thicknesses. However, for cylinders with a wall thickness of less than 4 mm, the difference between the minimum and maximum wall thicknesses of the shell measured on the same cross-section shall be less than or equal to 0,8 mm.

6.9 Stability

For a cylinder designed to stand on its base, the deviation from vertical shall be less than 1 % of its height, and the outer diameter of the surface in contact with the ground shall be greater than 75 % of the nominal outside diameter (D_o).

7 Tests and examinations

7.1 General

Every cylinder submitted to any test shall be identifiable to the batch, and either to the welder and welding machine, or in the case of an automatic machine to the welding machine.

7.2 Mechanical tests

7.2.1 General requirements

All mechanical tests for checking the quality of the metal used for gas cylinders shall be carried out on material taken from cylinders on which all operations affecting mechanical properties have been completed. They do not need to have been pressure tested.

The mechanical tests shall be carried out in accordance with 7.2.2 to 7.2.8, ISO 6892 and ISO 6506-1.

7.2.2 Types of test and evaluation of test results

The number, the localization and type of test specimens shall be taken as shown in Figure 3 and the tests shall be performed as specified in 7.2.3 to 7.2.8. If the cylinder is a sphere or has a design where a dome and/or a base does not exist, specimens shall be taken according to the requirements for the cylinder sidewall.

7.2.3 Tensile test on parent material

7.2.3.1 The test piece on which the tensile test is carried out shall conform to the provisions of ISO 6892. The two faces of the test piece corresponding to the internal and external walls of the cylinder shall not be machined.

7.2.3.2 The elongation after fracture shall not be less than 12 %.

7.2.3.3 The value obtained for tensile strength shall not be less than R_g . The value obtained for the yield stress (R_{ea}), as defined in 3.1.1, during the tensile test shall not be less than R_e .

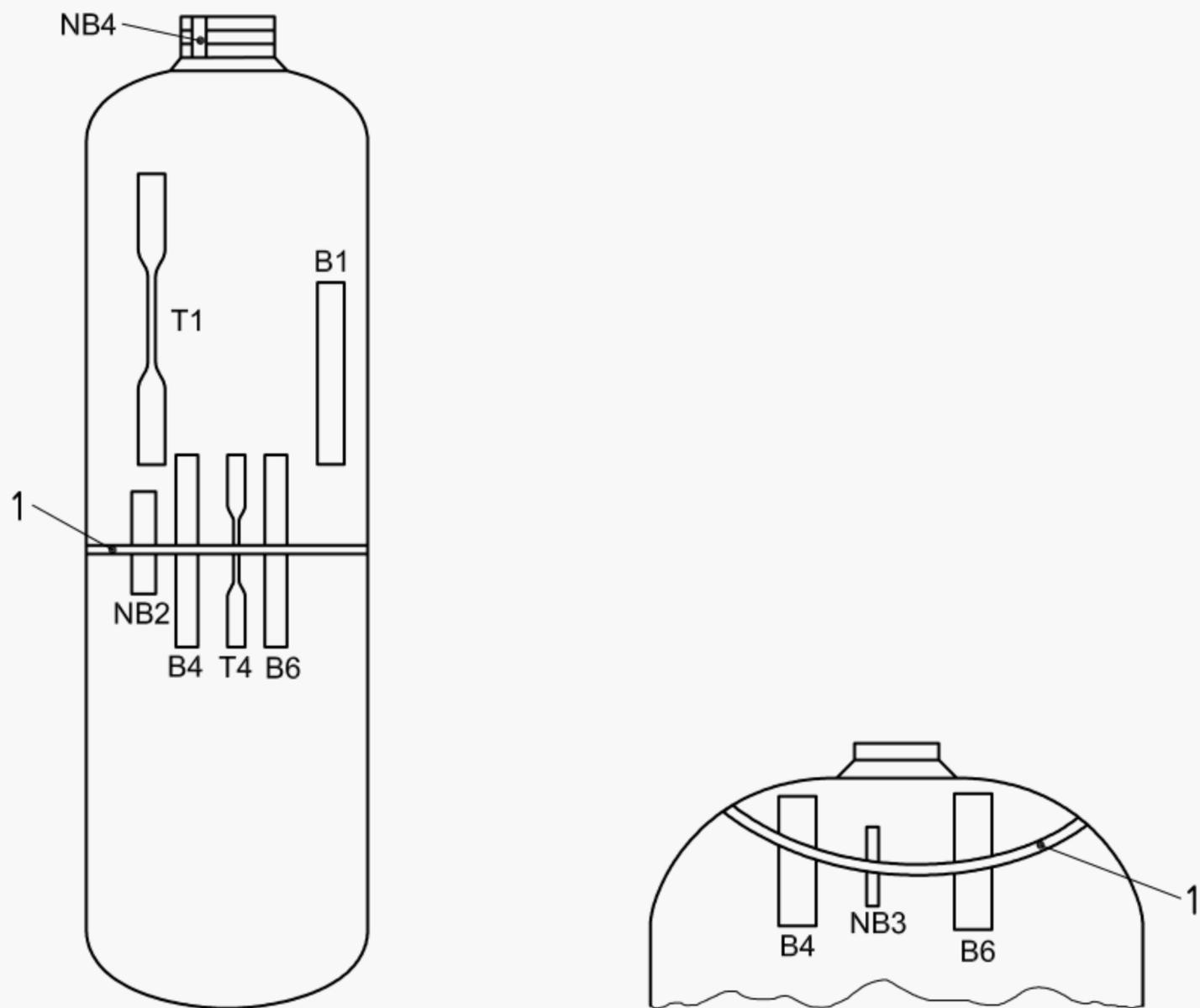
7.2.4 Tensile test in the pressure-bearing welds

The test specimens T3 and T4 (see Figure 3) shall be cut transversely to the weld and shall be the full thickness of the material at the welded joint. The shape and dimension of the test specimen shall be as shown in ISO 15614-2.

In preparing the test specimens, the face and back shall not be machined except to remove the backing strip or the tongue of a joggle joint. The face and back of the test piece shall each represent the surface of the parent material and the weld.

The ends of the test specimens may be carefully straightened cold as necessary in order to place them in the testing machine.

The tensile strength shall be not less than that specified for the parent material.



Where the samples can be procured, the weld should be perpendicular to the longitudinal axis of the sample.

a) Cylinders with circumferential seams only

b) Cylinders with a boss/bung weld only

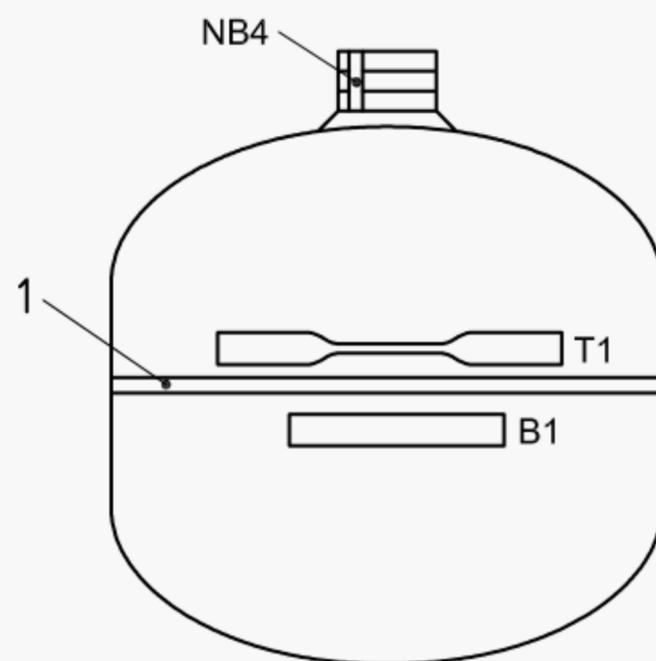
Key

- 1 weld
- T1 tensile test on parent material
- T4 tensile test on welded joint
- B1 bend test on parent material

- B4 bend test on weld, outer surface in tension
- B6 bend test on weld, inner surface in tension
- NB2 nick-break test on weld
- NB3 nick-break test on weld
- NB4 nick-break test on weld

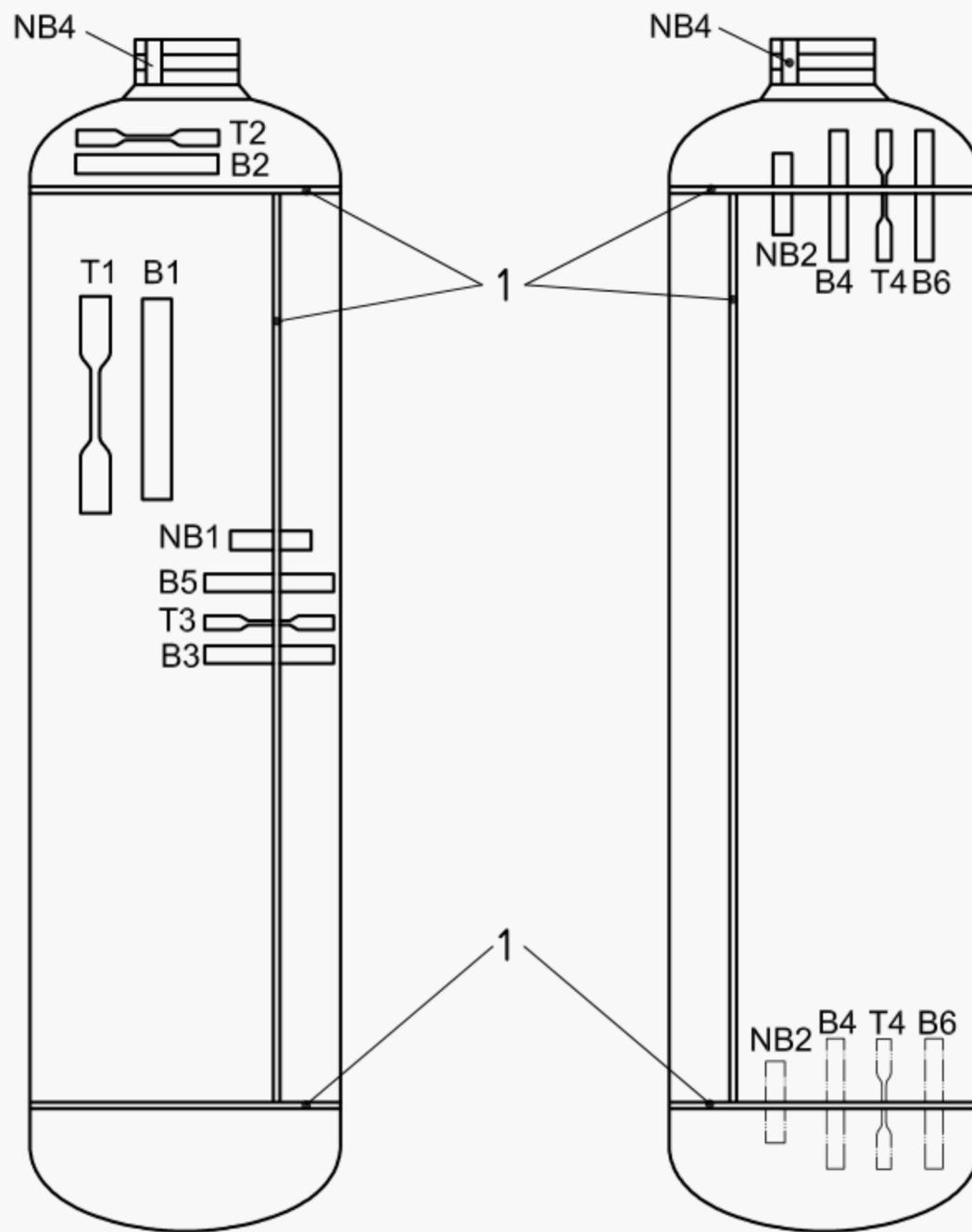
NOTE The location of specimens around the circumference of the cylinder is not specified.

Figure 3 — Location of test specimens in a cylinder



c) Cylinders with circumferential seams only: alternative positions for T1 and B1

Figure 3 (continued)



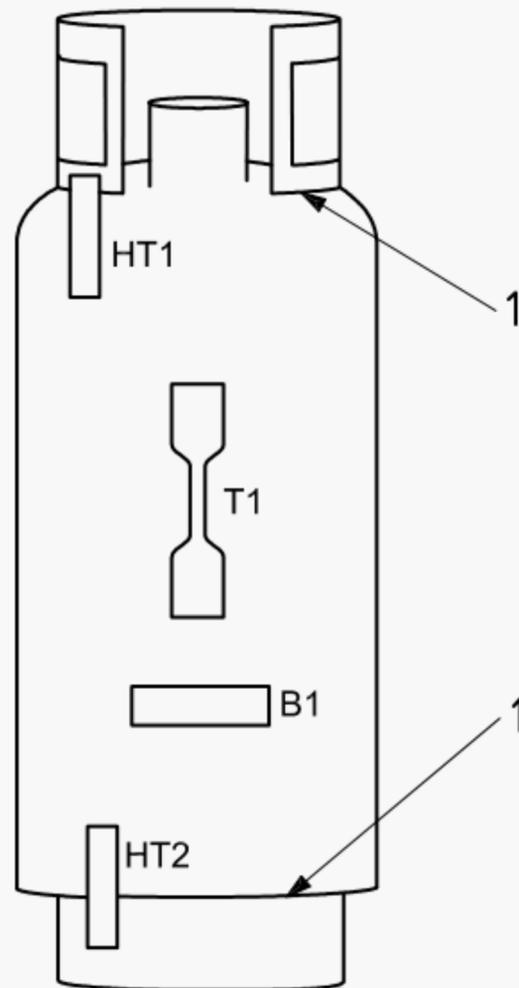
d) Cylinders with longitudinal and circumferential seams

Key

- | | | | |
|----|---------------------------------|-----|---|
| 1 | weld | B3 | bend test on weld, outer surface in tension |
| T1 | tensile test on parent material | B4 | bend test on weld, outer surface in tension |
| T2 | tensile test on parent material | B5 | bend test on weld, inner surface in tension |
| T3 | tensile test on weld | B6 | bend test on weld, inner surface in tension |
| T4 | tensile test on weld | NB1 | nick-break test on weld |
| B1 | bend test on parent material | NB2 | nick-break test on weld |
| B2 | bend test on parent material | NB4 | nick-break test on weld |

For positions of specimens across circumferential welds, alternate on successive cylinders between the positions indicated by full lines and those indicated by dash-dotted lines.

Figure 3 (continued)



e) Cylinders with seamless bodies with a welded shroud and foot-ring

Key

- 1 weld
- T1 tensile test on parent material
- B1 bend test on parent material
- HT1 and HT2 hardness test specimens

Figure 3 (continued)

7.2.5 Bend test on parent material

7.2.5.1 The bend tests shall be carried out on two test pieces obtained by cutting a ring of width 25 mm or, if greater, $3a'$ (± 1 mm) into equal parts. Each ring may be machined only on the edges. These edges may be rounded to a radius of no more than one tenth of the thickness of the test pieces or chamfered at an angle of 45° and a width of less than one tenth of the thickness of the test pieces.

7.2.5.2 The bend tests shall be carried out using a former of diameter d and two rollers separated by a distance of $d + 3a'$. During the test the inside face of the ring shall remain in contact with the former. Several test pieces can be tested at the same time on the same test machine.

7.2.5.3 The test piece shall not crack when bent inwards around the former until the inside edges are not further apart than the diameter of the former (see Figure 4).

7.2.5.4 The ratio (n) between the diameter of the former and the thickness of the test piece shall not exceed the values given in Table 3.

Table 3 — Bend test requirements

Actual tensile strength, R_m MPa	Value of n
$R_m \leq 220$	5
$220 < R_m \leq 330$	6
$330 < R_m \leq 440$	7
$R_m > 440$	8

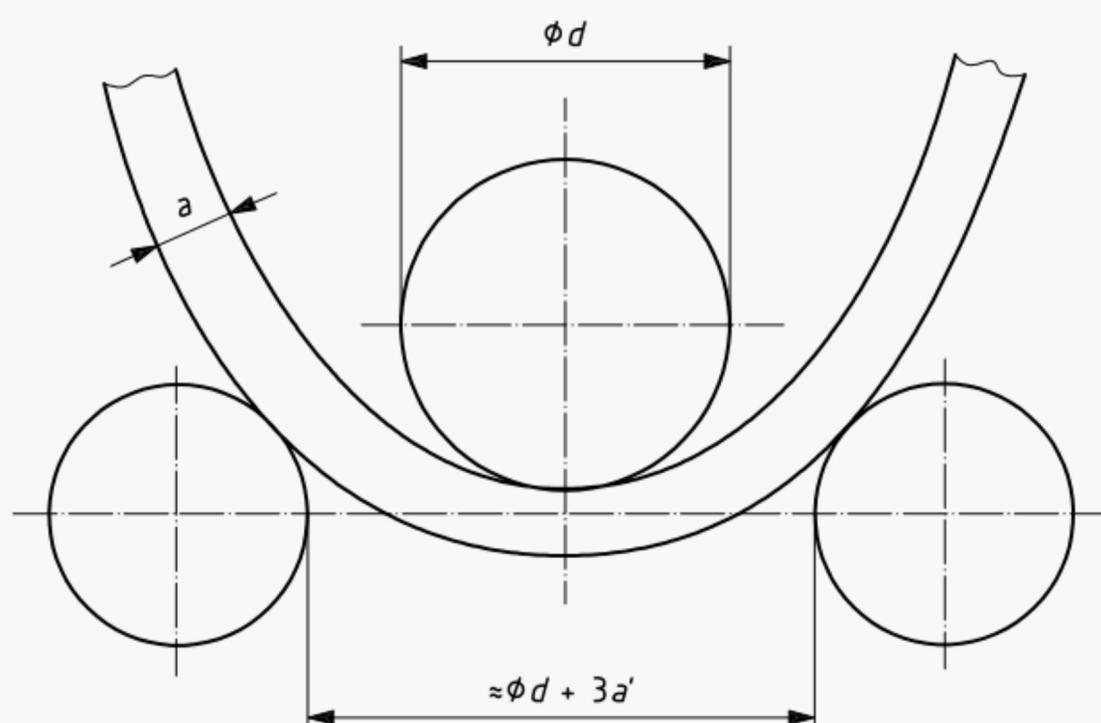


Figure 4 — Illustration of bend test on parent metal

7.2.6 Bend test across the welds

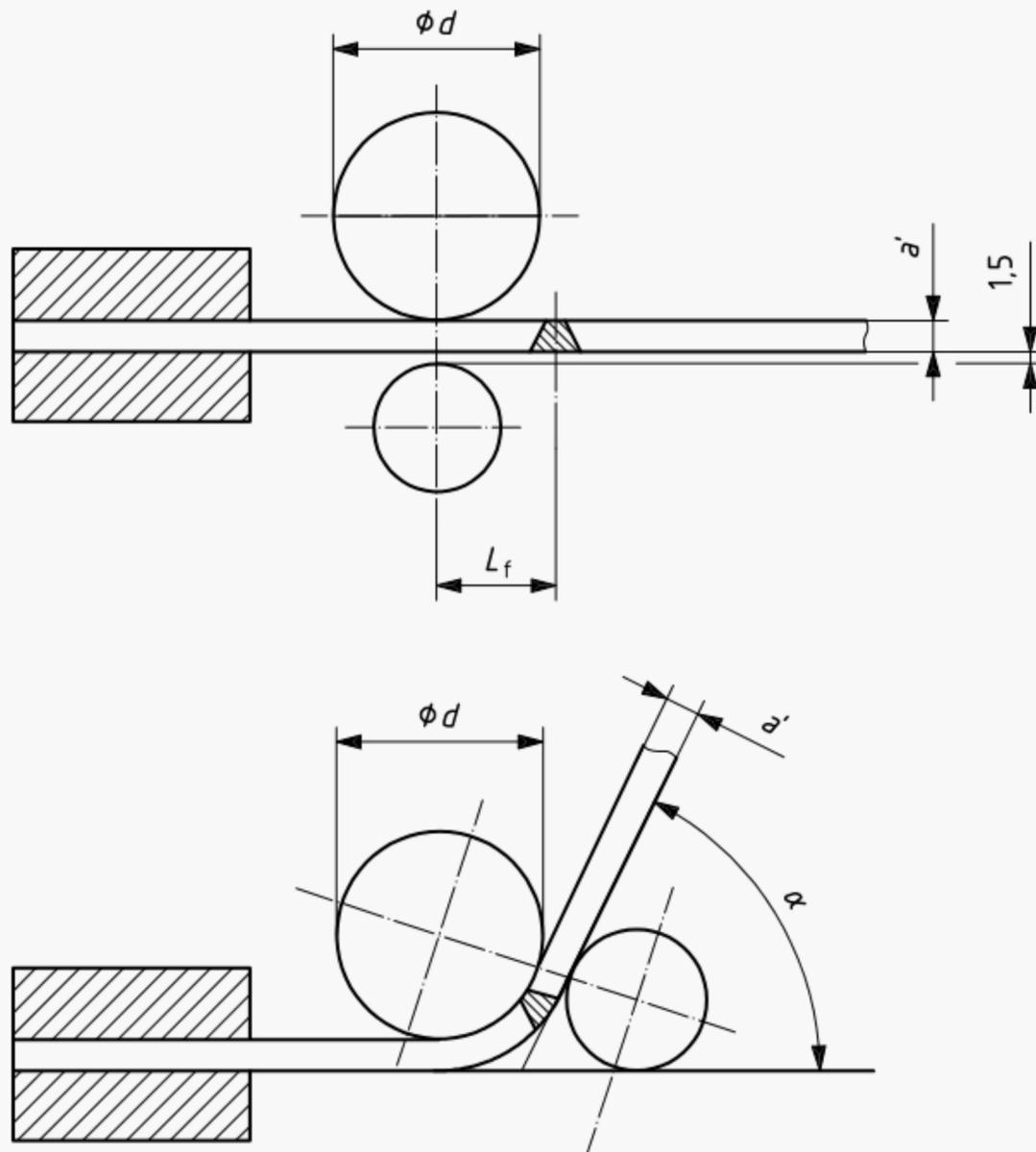
The width of the test specimen shall be in accordance with ISO 7438 and the length shall be such that it will satisfy the requirements of this test. In preparing the test specimen the corners shall be rounded off and in addition the backing strip or the tongue of a joggle joint, all excess weld metal and any weld reinforcement shall be machined off. This test shall be carried out in accordance with ISO 6892 (see Figure 5).

The former diameter (d) shall be 10 times the specimen thickness.

Test specimens B3 and B4 (see Figure 3) shall be bent with the outer surface of the weld in tension and test specimens B5 and B6 (see Figure 3) with the inner surface of the weld in tension. The inner and outer surfaces shall be ground flush. With reference to Figure 5, an angle α of 75° is required in addition to any pre-existing curvature (e.g. the curvature on samples taken from the boss/bung region).

For cylinders of outside diameter less than 120 mm, the bend test may be replaced by a nick-break test on the welds as shown in Figure 6. For cylinders designed as shown in Figure 3 c), the bend test may be replaced by a nick-break test on the welds if the diameter of the boss/bung weld is less than 120 mm.

After bending, the inner and outer surfaces and the sides of the test specimen shall be examined and shall be free from cracks.

**Key**

L_f distance from centre of roller to the weld prior to forming

$$0,7d < L_f < 0,9d$$

Figure 5 — Illustration of bend test across the welds

7.2.7 Nick-break test on the pressure-bearing welds

Nick-break tests shall be carried out on test specimens NB1, NB2, NB3 and NB4 (see Figure 3), which shall be prepared in the same way as those required for the bend tests (see 7.2.6) except that a slot shall be cut along the weld on each side at the centre line. The slot shall be of a form shown in Figure 6 except that for the test specimens NB3 and NB4 the dimensions and the form shall be modified as necessary to suit the design of the cylinder. The specimens shall then be broken cold in the weld and the fracture shall reveal a sound, homogeneous weld with complete penetration, free from oxide or other inclusions or excessive porosity.

Dimensions in millimetres

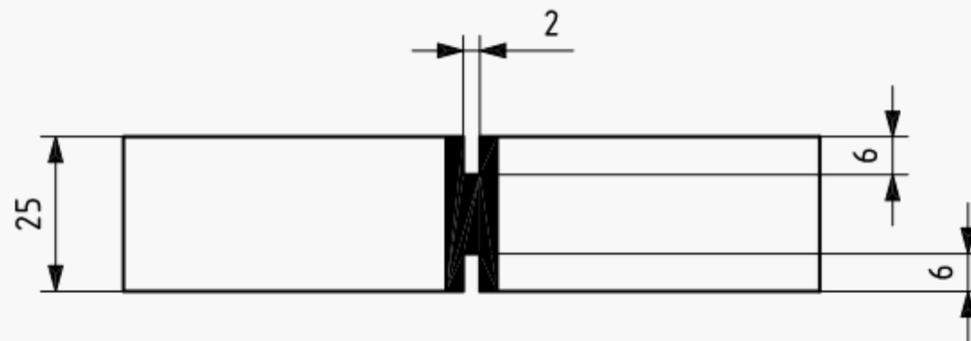


Figure 6 — Nick-break test on weld

7.2.8 Hardness test

For cylinders with seamless bodies, the hardness test of ISO 7866 applies. Hardness tests shall be performed on all cylinders on the parent material and on a batch basis for welded additions.

Additionally, for the cylinders with a seamless body with welded shroud and foot-ring, the hardness test shall be carried out on the test specimens HT1 and HT2 (see Figure 3). The tests shall be carried out on the cross-section area of the specimens taken from the shroud and foot-ring welds, respectively. The hardness in the parent metal, welded and heat-affected zone shall be equal to or greater than the minimum guaranteed hardness.

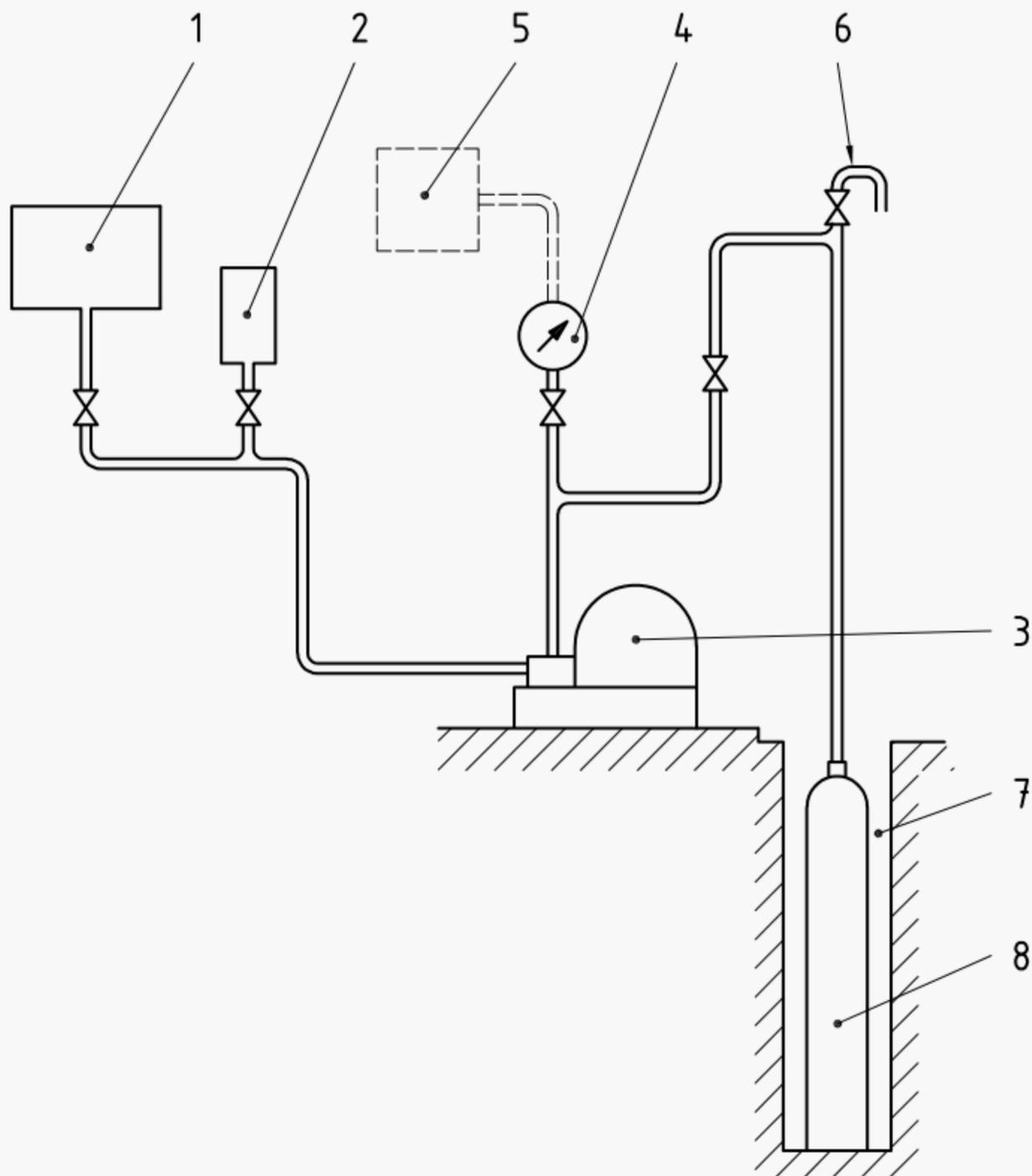
7.3 Hydraulic burst test

7.3.1 Test conditions

7.3.1.1 All welding shall be completed on cylinders subjected to this test, which shall bear markings in accordance with ISO 13769.

7.3.1.2 The hydraulic burst test shall be carried out using a test rig which allows pressure to be increased at a controlled rate until the cylinder bursts and the curve of pressure variation versus volumetric expansion to be produced. The test shall be carried out at room temperature. (The temperature of the cylinder shall be less than 40 °C.) See Figure 7.

7.3.1.3 During the first stage (elastic deformation), the rate of increase in pressure shall be approximately constant up to the level at which plastic deformation starts. The duration of the test shall not be less than 2 min.



Key

- 1 test fluid reservoir
- 2 tank for measurement of test fluid (The feed tank may 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 cylinder

Figure 7 — Typical hydraulic burst test installation

7.3.2 Interpretation of test

7.3.2.1 The interpretation of the burst test shall involve

- determination of the maximum pressure (p_b) and of the yield pressure (p_y) attained during the test;
- determination of the volumetric expansion (V_{exp}) attained at burst;
- visual examination of the tear and of the shape of its edges;
- verification, in the case of cylinders with a concave base, that the base of the cylinder shows no visible sign of having been reversed.

7.3.2.2 The measured burst pressure (p_b) shall be

$$p_b \geq 2,0 \times p_h$$

The observed yield pressure (p_y) shall be

$$p_y \geq 1/F \times p_h$$

The specific change in volume of the cylinder is given by $\frac{100(V - V_0)}{V_0}$

where

V is the capacity of the cylinder subsequent to bursting,

V_0 is the capacity of the cylinder before expansion.

The volumetric expansion (V_{exp}) shall be

$$V_{\text{exp}} \geq 8 \%$$

7.3.2.3 The burst test shall not cause fragmentation of the cylinder. The cylinder shall remain in one piece.

7.3.2.4 The main tear shall not be of a brittle type. In addition, for cylinders of actual wall thickness less than 13 mm other than spherical cylinders, the fracture shall be acceptable only if it conforms to the following description.

- The edges of the fracture shall not be radial but shall be sloping in relation to a diametrical plane and shall display a contraction.
- At each end of the fracture, a maximum of two branches shall be allowed and in this case the shorter branch at each end shall be less than 20 mm long.
- The fracture shall not extend more than 90° around the circumference on either side of its main part.
- The fracture shall not extend into those parts of the cylinder of thickness more than 1,5 times the maximum thickness measured halfway up the cylinder. For cylinders with convex bases, the fracture shall not reach the centre of the cylinder base.

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

7.3.2.5 The tear shall not reveal any obvious defect in the metal.

7.4 Pressure-cycling test

7.4.1 Cylinders subjected to this test shall bear markings in accordance with ISO 13769.

7.4.2 This test shall be carried out with a non-corrosive liquid. Cylinders which are guaranteed by the manufacturer to be reasonably representative of the minimum values specified in the design shall be subjected to successive reversals at an upper cyclic pressure which is equal to the hydraulic test pressure (p_h). The cylinders shall withstand 12 000 cycles without failure.

The value of the lower cyclic pressure (p_{lc}) shall not exceed 10 % of the test pressure (p_h).

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

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

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

7.5 Hydraulic test

7.5.1 The water pressure in the cylinder shall increase at a controlled rate until the pressure p_h is reached.

7.5.2 The 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.

7.5.3 After the test the cylinder shall show no visible permanent deformation.

7.5.4 Any cylinder which does not fulfil this test requirement shall be rejected.

7.5.5 The hydraulic proof pressure test may be replaced by a pneumatic proof pressure test.

WARNING — Appropriate measures shall be taken to ensure safe operation and to contain any energy that may be released. It should be noted that pneumatic pressure tests require more precautions than hydraulic pressure tests since, regardless of the size of the container, any error in carrying out this test is highly likely to lead to a rupture under gas pressure. Therefore, these tests shall be carried out only after ensuring that the safety measures satisfy the safety requirements. Having decided to use one particular type of test, its results shall be final. The test pressure shall be in accordance with the stamp markings on the cylinder.

7.6 Check on the homogeneity of a batch

This test, which is carried out by the manufacturer on each cylinder, involves checking by means of a hardness test or other appropriate means that no error has been made in the choice of the original materials or in carrying out the heat treatment.

7.7 Leakage test

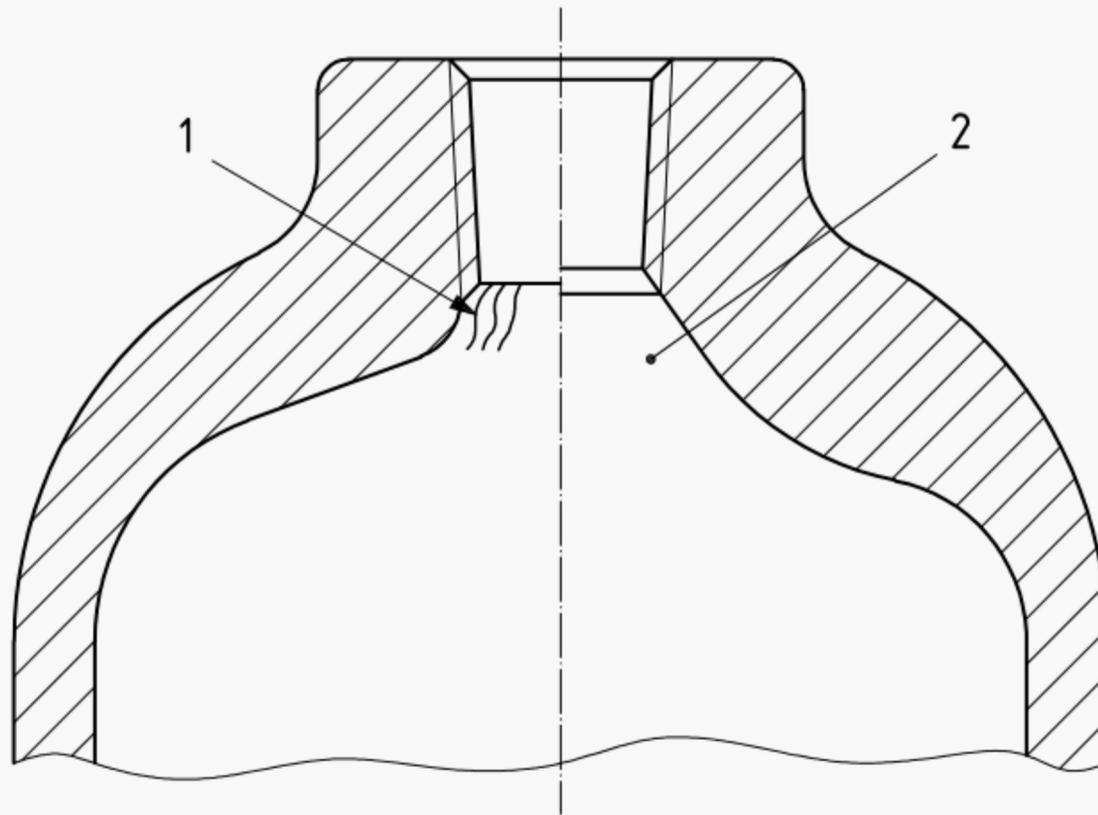
The manufacturer shall employ such manufacturing techniques and apply such tests as will demonstrate to the satisfaction of the inspector that the cylinders do not leak.

7.8 Capacity check

The manufacturer shall verify that the water capacity of each cylinder conforms to the design drawing.

7.9 Examination for neck folds

This subclause applies to cylinders with seamless bodies. Each cylinder shall be examined for neck folds (using an introscope, by tactile or ultrasonic examination, etc.). Folds that could compromise the performance of the cylinder and that are visible as lines running towards the threaded portion as shown on the left-hand side of Figure 8 shall be removed by a machining operation until the lines are no longer visible. After the machining operation the 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.

**Key**

- 1 folds before machining
- 2 folds after machining

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

8 Conformity evaluation

New design type testing and production testing shall be carried out in accordance with Annex B.

9 Identification marks

Cylinders shall be marked in accordance with ISO 13769.

10 Records

If the results of the checks are satisfactory, the cylinders shall be stamped in accordance with ISO 13769.

A batch test certificate shall be issued, a typical example of which is given in Annex D.

Annex A (normative)

Corrosion tests

A.1 Test for assessing susceptibility to intercrystalline corrosion

A.1.1 Principle

The test method specified below consists in simultaneously immersing the specimens taken from the finished 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 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 for parent material, weld material and associated heat-affected zones.

A.1.2 Taking specimens

Specimens shall be taken from the head, body and base of the cylinder (Figure A.1) and also from regions representative of weld material and associated heat-affected zones (Figure A.2) so that the tests with the solution as defined in **A.1.4.2.1** can be carried out on metal from all appropriate regions of the cylinder.

Each specimen shall be of the general shape and the dimensions indicated in Figure A.3.

The faces $a_1 a_2 a_3 a_4$, $b_1 b_2 b_3 b_4$, $a_1 a_2 b_2 b_1$, and $a_4 a_3 b_3 b_4$ shall all be sawn with a band saw and then carefully trimmed with a fine file. The surfaces $a_1 a_4 b_4 b_1$ and $a_2 a_3 b_3 b_2$, which correspond to the inner and outer faces of the cylinder, respectively, shall be left in their rough manufactured state.

A.1.3 Preparation of surface before corrosive etching

A.1.3.1 Products required

The following products are required:

- nitric acid (HNO_3) for analysis, density 1,33;
- hydrogen fluoride (HF) for analysis, density 1,14 (at 40 %);
- de-ionized water (H_2O).

A.1.3.2 Method

Prepare the following solution in a beaker.

- HNO_3 : 63 cm^3 .
- HF: 6 cm^3 .
- H_2O : 931 cm^3 .

Bring the solution to a temperature of 95 °C. Treat each specimen, suspended on an aluminium wire, in this solution for 1 min. Wash each specimen in running water and then in de-ionized water.

Immerse the specimen in nitric acid, as defined in **A.1.3.1**, for 1 min at room temperature to remove any copper deposit which may have formed. Rinse in de-ionized water.

To prevent oxidation of specimens, they should be plunged, as soon as they have been prepared, in 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 sodium chloride (NaCl) and 3 g/l hydrogen peroxide (H₂O₂).

A.1.4.2 Preparation of the corrosive solution

A.1.4.2.1 Products required

The following products are required:

- NaCl crystallized, for analysis;
- H₂O₂ 100 to 110 volumes - medicinal;
- potassium permanganate (KMnO₄) for analysis;
- sulphuric acid (H₂SO₄) for analysis, density 1,83;
- de-ionized water.

A.1.4.2.2 Titration of hydrogen peroxide

Since the hydrogen peroxide is not very stable, it is essential to check its titre before use. To do this take 10 cm³ of hydrogen peroxide with a pipette, dilute to 1 000 cm³ (in a gauged flask) with de-ionized water, thus obtaining a hydrogen peroxide solution which will be called C. With a pipette, place in an Erlenmeyer flask

- 10 cm³ of the hydrogen peroxide solution C;
- 2 cm³ approximately of sulphuric acid, density 1,83.

A solution of permanganate at 1,859 g/l shall be used for the titration. The permanganate itself serves as an indicator.

A.1.4.2.3 Explanation of titration

The reaction of the permanganate on the hydrogen peroxide in a sulphuric acid medium is expressed as



which gives the equivalence $316 \text{ g KMnO}_4 = 170 \text{ g H}_2\text{O}_2$

Therefore 1 g of pure hydrogen peroxide reacts on 1,859 g of permanganate; hence the use of a 1,859 g/l solution of permanganate, which saturates, volume for volume, 1 g/l hydrogen peroxide. Since the hydrogen peroxide was diluted 100 times to begin with, the 10 cm³ of the test sample represent 0,1 cm³ of the original hydrogen peroxide.

By multiplying by 10 the number of cubic centimetres of 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 l:

Dissolve 570 g of sodium chloride in de-ionized water to obtain a total volume of about 9 l. Add the quantity of hydrogen peroxide calculated below. Mix and then make up the volume to 10 l with de-ionized 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

$$\frac{1000 \times 30}{T}$$

A.1.4.3 Etching conditions

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

Either suspend the specimen in the corrosive solution by means of an aluminium wire or place the specimen in the solution so that it rests only on the corners, the second method being preferable. The etching time shall be six hours and the temperature fixed at (30 ± 1) °C to ensure that the quantity of reagent is at least 10 cm³ 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 again in water and dry with compressed air.

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

A.1.5 Preparation of specimens for examination

A.1.5.1 Products required

The following products are required.

- Casting dishes with, for example, the following dimensions:
 - external diameter: 40 mm;
 - height: 27 mm;
 - wall thickness 2,5 mm.
- Resin plus hardener.

A.1.5.2 Method

Place each specimen vertically in a casting dish so that it rests on its face $a_1 a_2 a_3 a_4$. Pour a mixture of resin and hardener around it in the appropriate proportion. The usual setting time is about 24 h.

Remove a certain amount of material from the face $a_1 a_2 a_3 a_4$, preferably by lathe, so that the section $a'_1 a'_2 a'_3 a'_4$ examined under the microscope cannot show corrosion from the surface $a_1 a_2 a_3 a_4$. The distance between the faces $a_1 a_2 a_3 a_4$ and $a'_1 a'_2 a'_3 a'_4$, i.e. the thickness removed by the lathe, shall be at least 2 mm (Figures A.3 and A.4). The section for examination shall be polished mechanically with alumina, first on paper and then on felt.

A.1.6 Micrographic examination of specimens

The examination consists in noting the intensity of intercrystalline corrosion on the part of the perimeter of the section to be examined (see A.1.7). When doing this, take account of the properties of the metal both on the outer and inner surfaces of the cylinder and in the thickness of the latter.

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

A.1.7 Interpretation of the micrographic examination

This consists in verifying that intergranular corrosion is superficial.

For alloys with equiaxed crystallization, the depth of corrosion round the entire perimeter of the section shall not exceed the higher of the following two values:

- three grains in the direction perpendicular to the face examined;
- 0,2 mm.

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

For alloys with crystallization set in one direction through cold working, the depth of the corrosion into each of the two faces which make up the internal and external surfaces of the cylinder shall not exceed 0,1 mm.

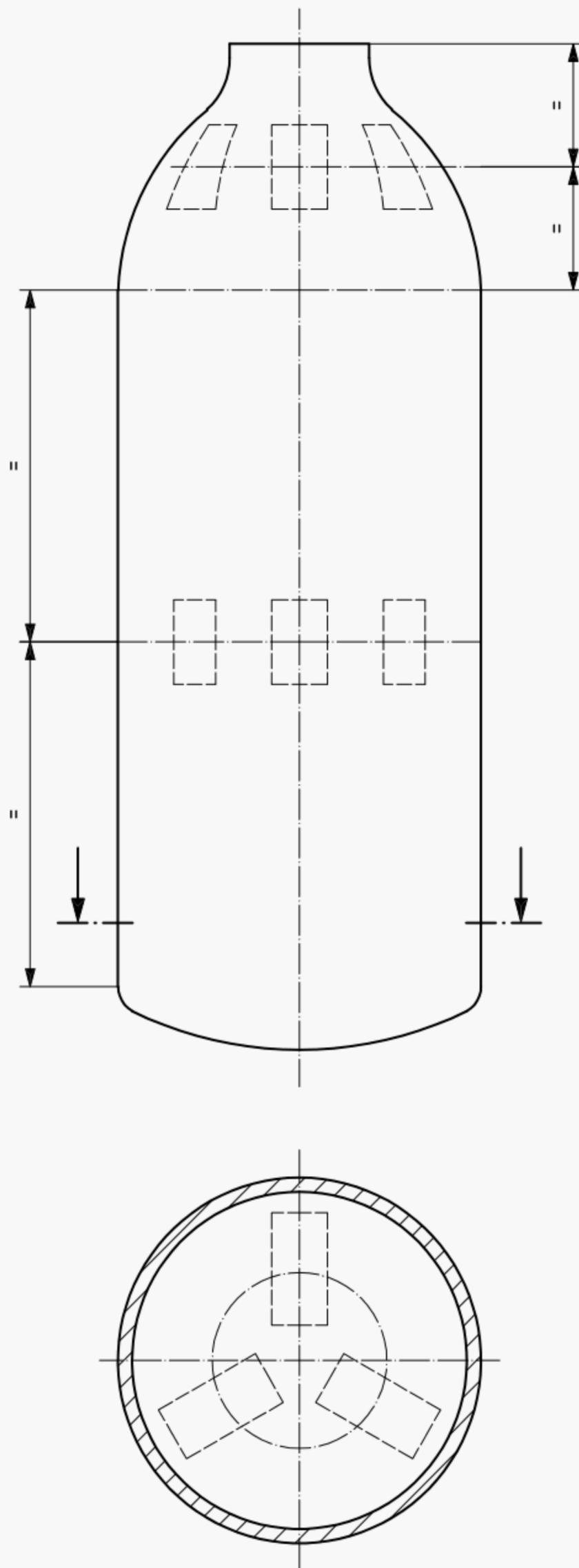
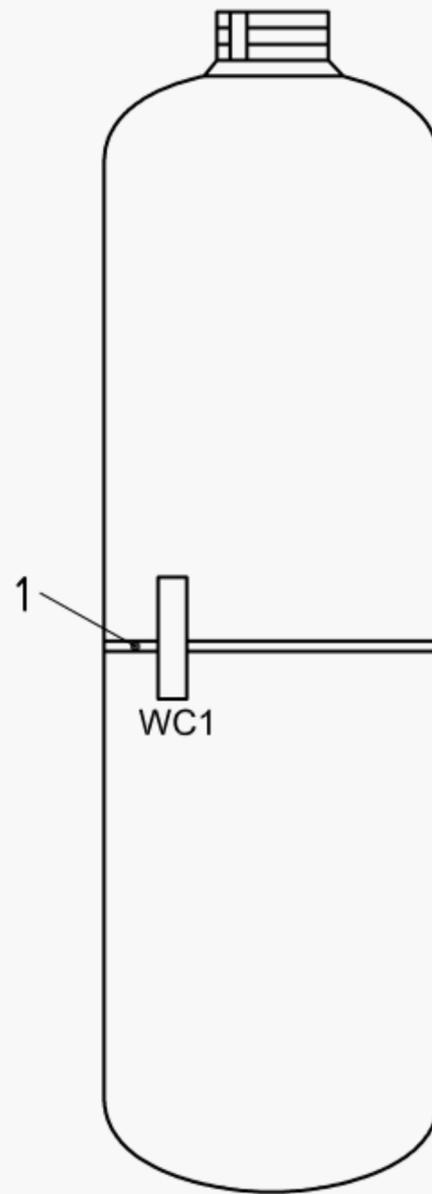
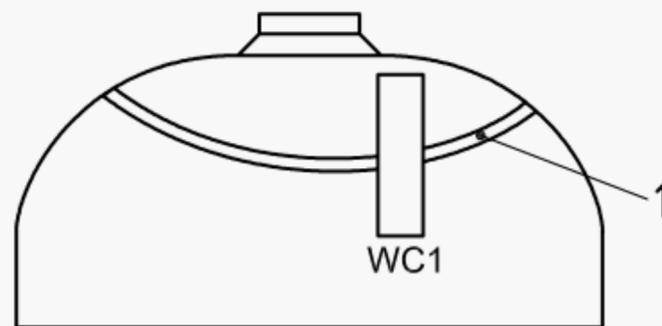


Figure A.1 — Location of specimens — parent material



a) Cylinders with circumferential seams only



b) Cylinders with a boss/bung weld only

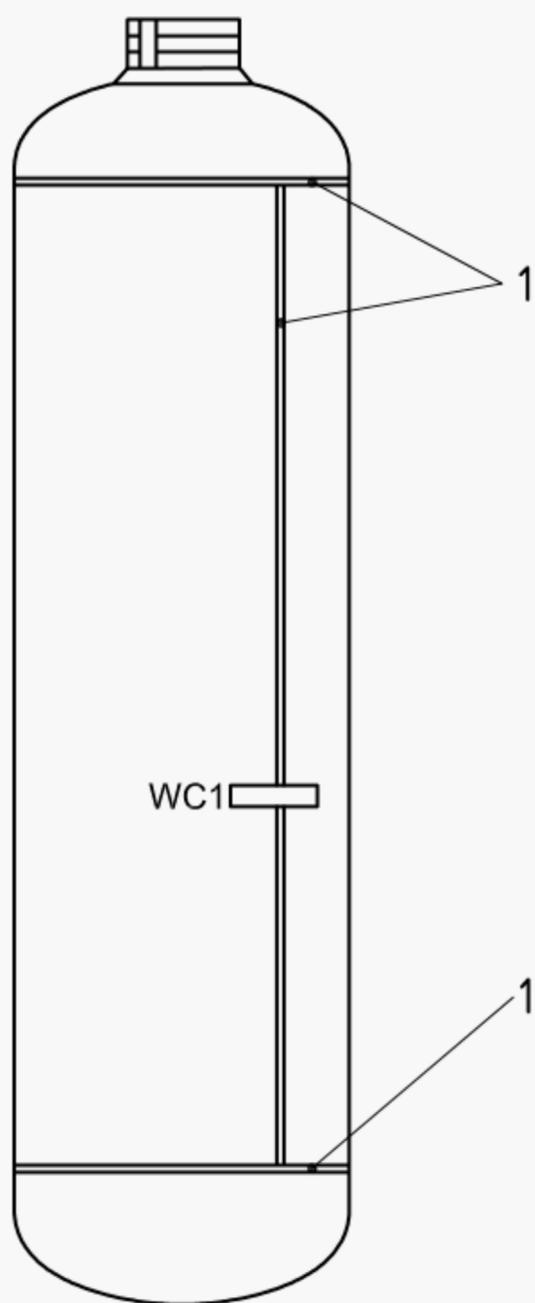
Key

1 weld

WC1 Weld intercrystalline corrosion test.

Where the samples can be procured, the weld should be perpendicular to the longitudinal axis of the sample.

Figure A.2 — Location of specimens — weld material



c) Cylinders with longitudinal and circumferential seams



d) Cylinders with seamless bodies with a welded shroud and foot-ring

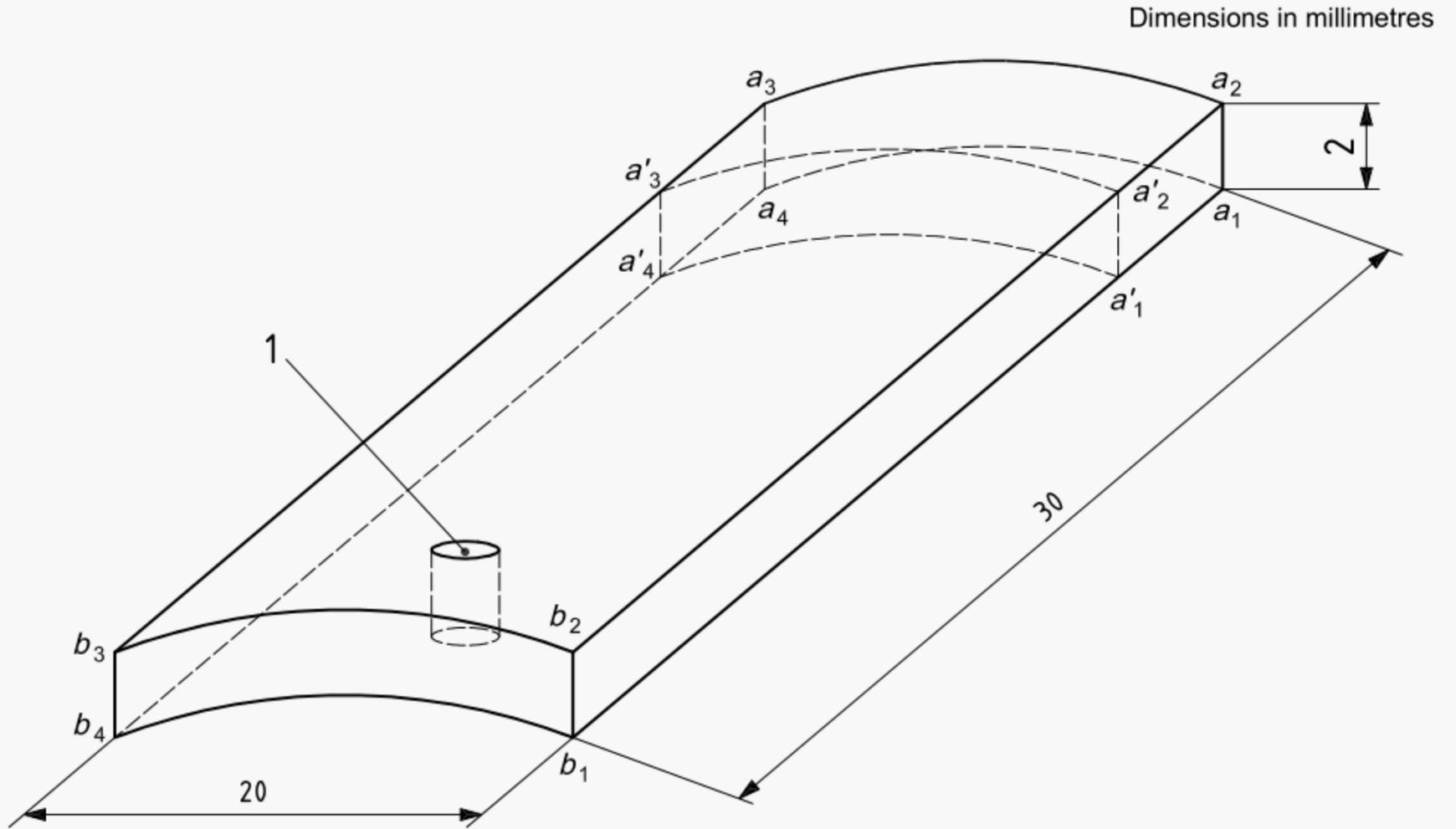
Key

1 weld

WC1 Weld intercrystalline corrosion test.

WC2 Weld intercrystalline corrosion test.

Figure A.2 (continued)



Key

- 1 hole, 3 mm diameter
- 2 thickness of cylinder

Figure A.3 — Specimen shape and dimensions — parent material

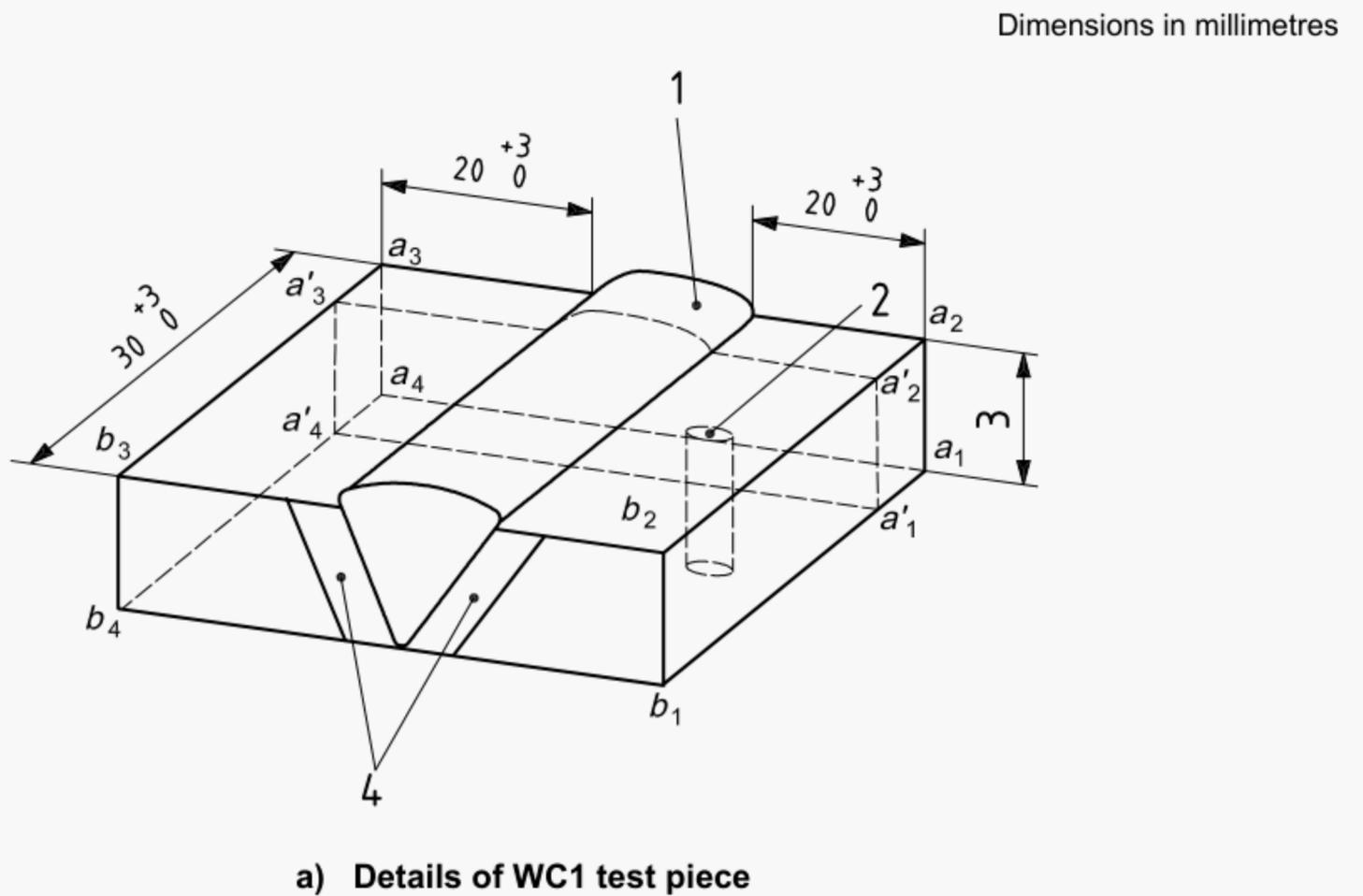
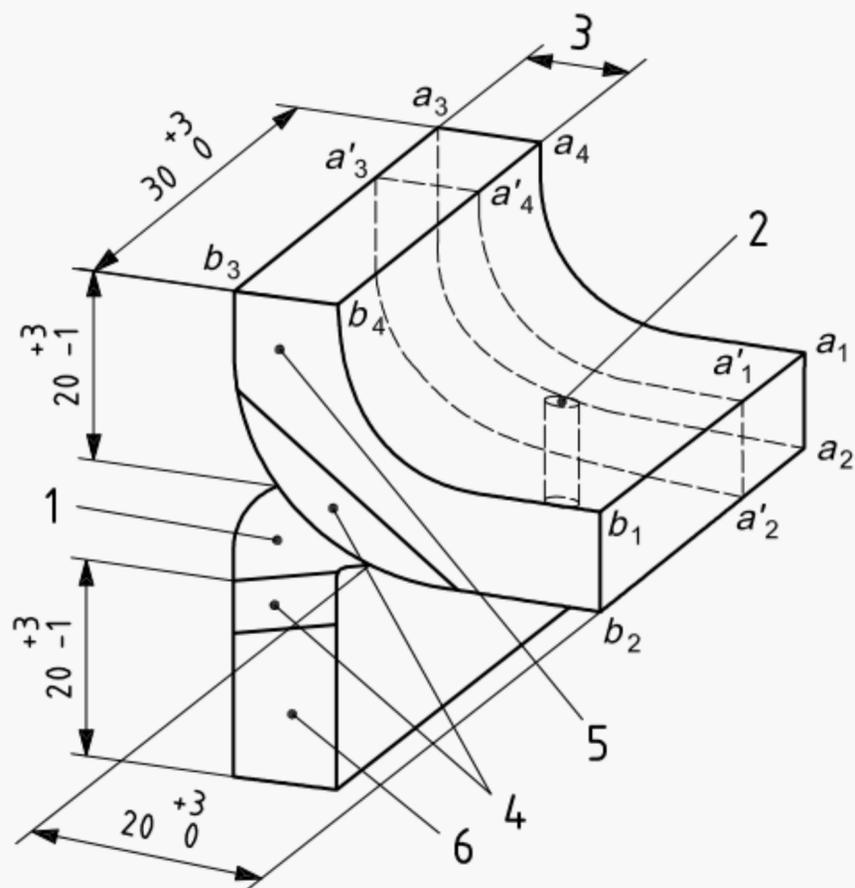


Figure A.4 — Specimen shape and dimensions — weld material

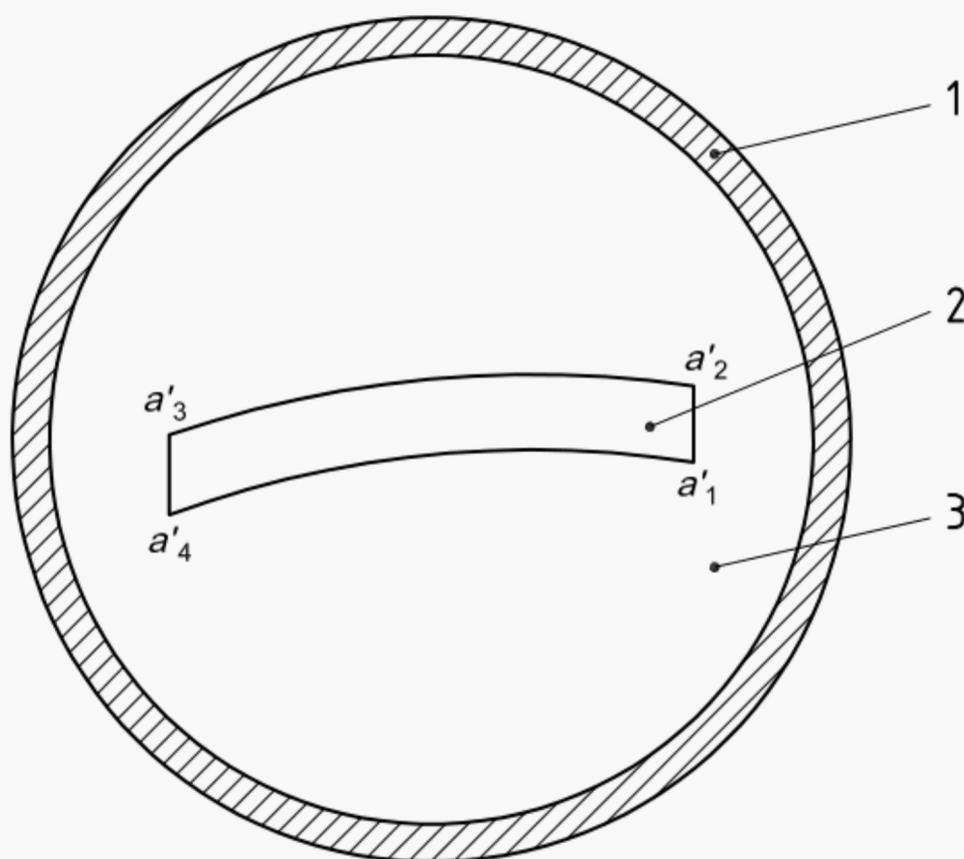


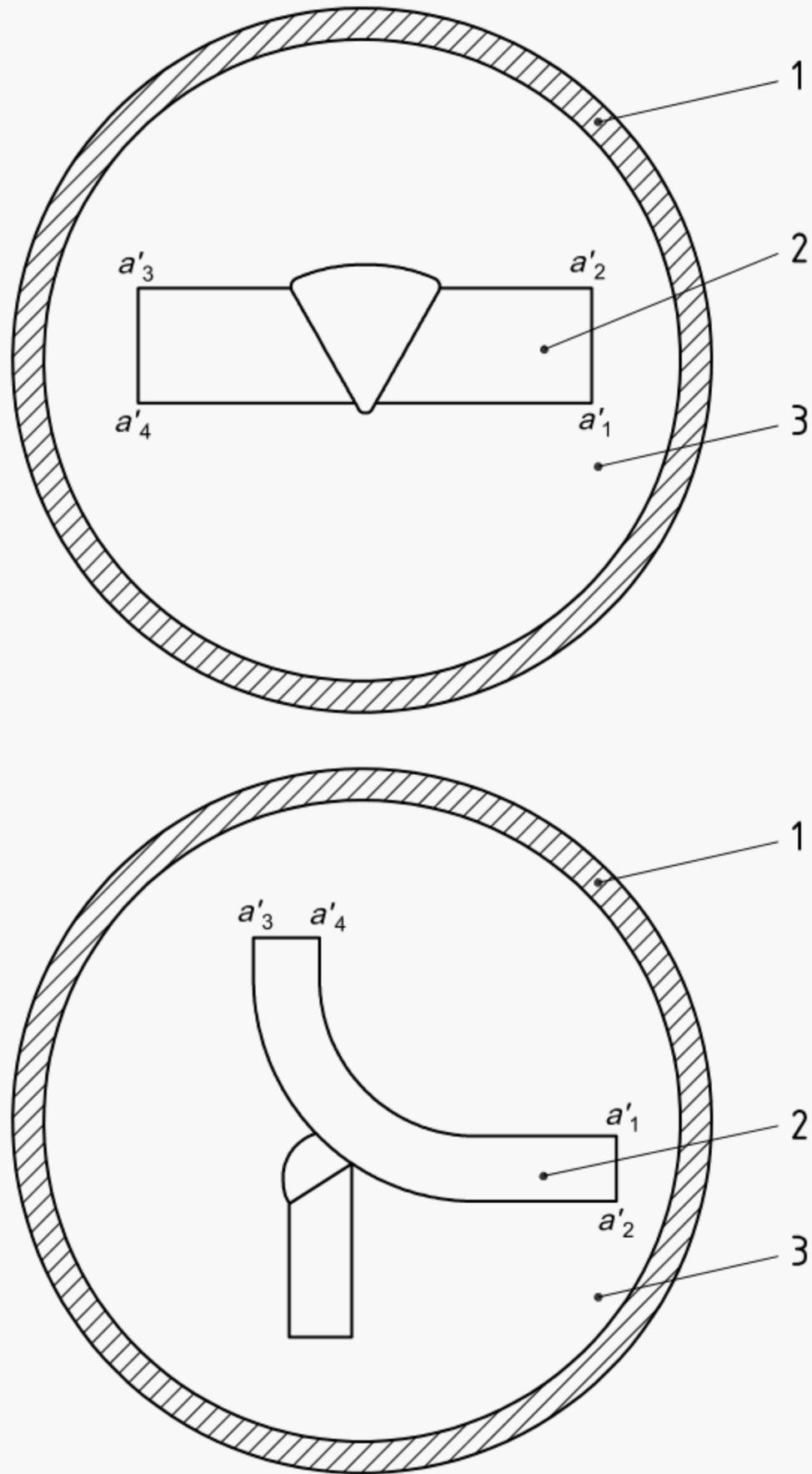
b) Details of WC2 test piece

Key

- | | | | | | |
|---|---------------------|---|-----------------------|---|-----------|
| 1 | weld | 3 | thickness of cylinder | 5 | cylinder |
| 2 | hole, 3 mm diameter | 4 | heat-affected zone | 6 | foot-ring |

Figure A.4 (continued)





Key

- 1 casting dish
- 2 cylinder specimen
- 3 resin matrix

Figure A.5 — Specimens in casting dish

A.2 Tests for assessing susceptibility to stress corrosion

A.2.1 Principle

The method specified below consists of the subjection to stress of rings cut from the cylindrical part of the cylinder, their immersion in brine for a specified period, followed by removal of the brine and exposure to the air for a longer period and repetition of this cycle for 30 d. If there are no cracks in the rings after the period of 30 d, the alloy can be considered suitable for the manufacture of gas cylinders.

A.2.2 Taking specimens

Cut three rings with a width of $4a'$ or 25 mm, whichever is the greater, from the cylindrical part of the cylinder (see Figure A.6). The specimens shall have a 60° cut-out and be subjected to stress by means of a threaded bolt and two nuts (see Figure A.7).

A.2.3 Surface preparation before corrosion test

All traces of grease, oil and adhesive used with stress gauges (see A.2.4.2.3) shall be removed with a solvent.

A.2.4 Performance of the test

A.2.4.1 Preparation of the corrosive solution

A.2.4.1.1 Prepare the brine by dissolving $3,5 \pm 0,1$ parts by mass of sodium chloride in 96,5 parts by mass of water.

A.2.4.1.2 The pH value of the freshly prepared solution shall be in the range 6,4 to 7,2.

A.2.4.1.3 The pH may be corrected only by using dilute hydrochloric acid or dilute sodium hydroxide.

A.2.4.1.4 The solution shall not be topped up by adding the salt solution described in A.2.4.1.1, but only by adding distilled water up to the initial level in the vessel. Topping up may be carried out daily if necessary.

A.2.4.1.5 The solution shall be completely replaced every week.

A.2.4.2 Applying the stress to the rings

A.2.4.2.1 Three rings are to be compressed so that the outer surface is under tension.

A.2.4.2.2 The tensile stress reached on the external face of the test specimen shall be equal to $R_e/1,3$.

A.2.4.2.3 The actual stress may be measured by electric stress gauges.

A.2.4.2.4 The diameter of the compressed ring to achieve the required stress may be calculated using the following equation:

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

in which

D' is the diameter of the ring when compressed in millimetres;

D is the external diameter of the cylinder in millimetres;

t is the cylinder wall thickness in millimetres.

- R is the tensile stress reached on the external face of the test specimen, equal to $R_e/1,3$, in megapascals;
- E is the modulus of elasticity in megapascals = 70 000 MPa approximately;
- z is the correction factor (Figure A.8).

A.2.4.2.5 The nuts and bolts shall be electrically insulated from the rings and protected from corrosion by the solution.

A.2.4.2.6 The three rings shall be completely immersed in the saline solution for 10 min.

A.2.4.2.7 They shall then be removed from the solution and exposed to the air for 50 min.

A.2.4.2.8 This cycle shall be repeated for 30 d or until the ring breaks, whichever happens first.

A.2.4.2.9 The specimens shall be inspected visually for any cracks.

A.2.5 Interpretation of the results

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

A.2.6 Possible metallographical examination

A.2.6.1 In the event of doubt about the presence of cracks (e.g. line of pitting), uncertainty may be removed by means of an additional metallographical examination of a section taken perpendicular to the axis of the ring in the suspect area (see Figure A.6). 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 the outer face of the ring reveals inter-crystalline cracks which are clearly deeper than the corrosion affecting the inner face, the ring shall be considered to have failed the test.

A.2.7 Reports

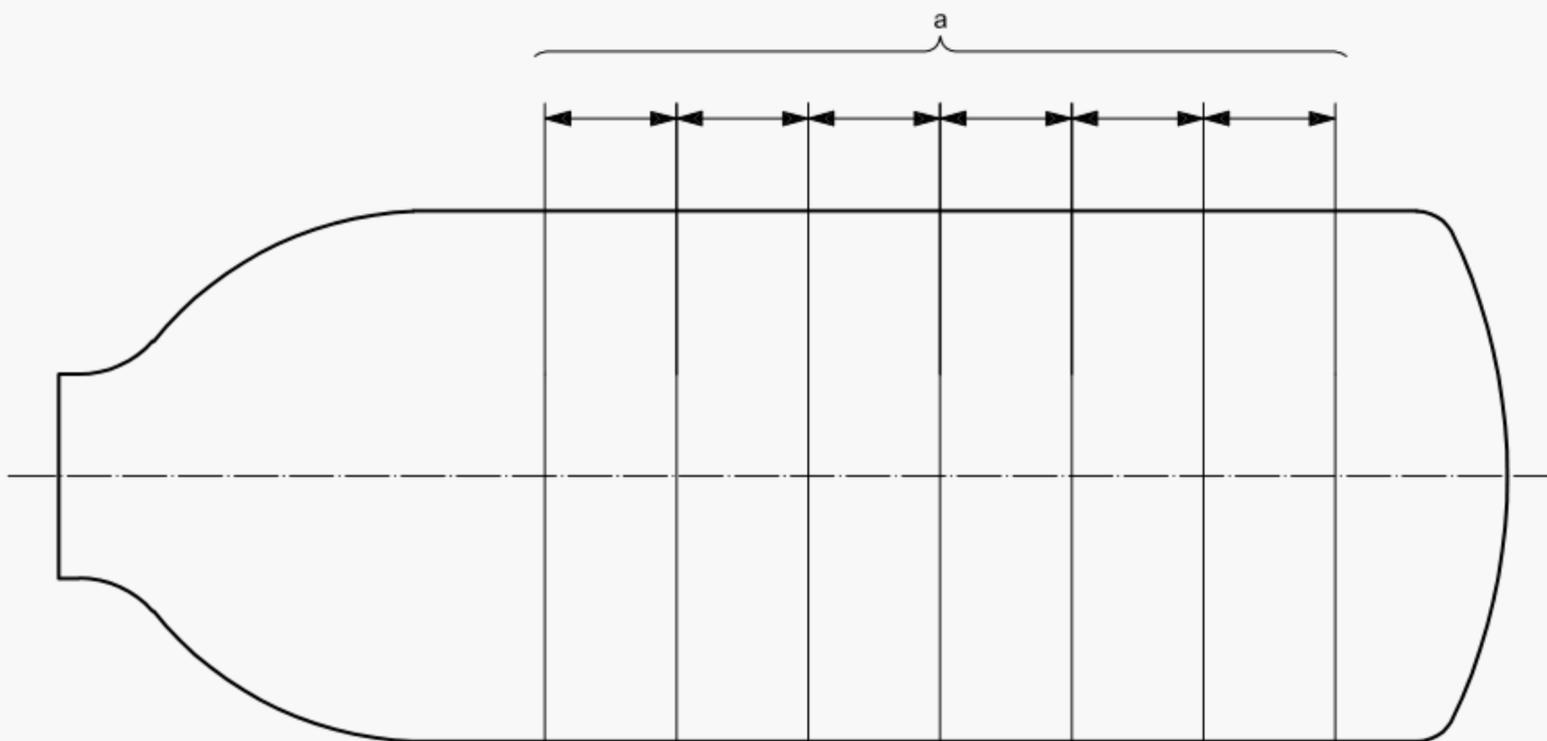
A.2.7.1 The name of the alloy and/or its standard number shall be indicated.

A.2.7.2 Composition limits of the alloy shall be given.

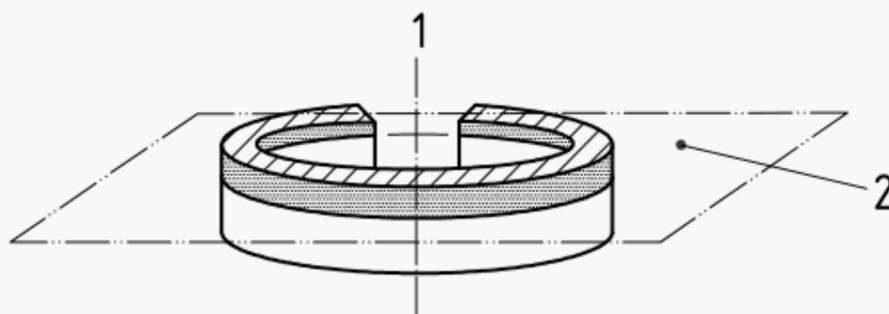
A.2.7.3 The actual analysis of the cast from which the cylinders were manufactured shall be mentioned.

A.2.7.4 The actual mechanical properties of the alloy shall be reported, together with the minimum mechanical property requirements.

A.2.7.5 The result of the test shall be given.



a) Location of specimen rings

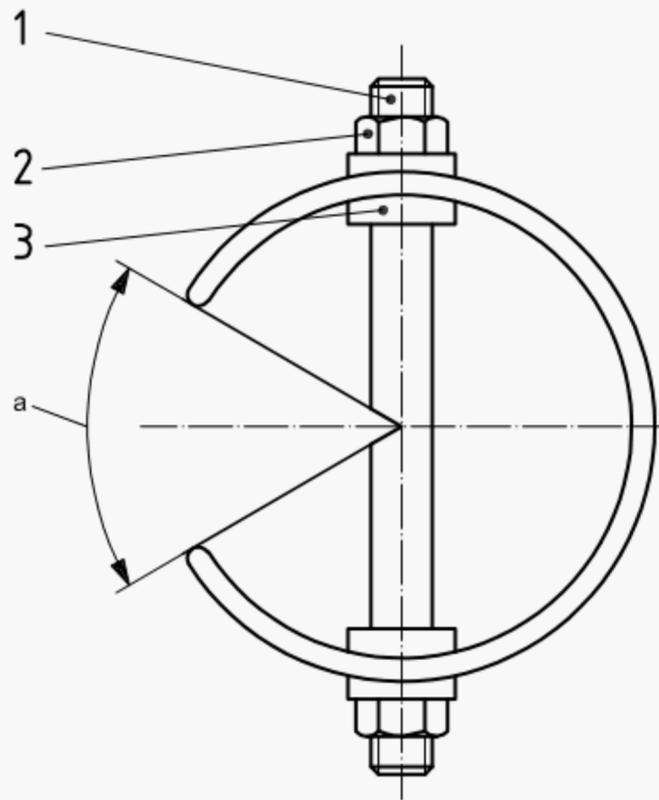


b) Section for additional metallographical examination

Key

- 1 axis
- 2 perpendicular plane
- a $4a'$ or 25.

Figure A.6 — Specimen rings



Key

- 1 threaded bolts
- 2 nut
- 3 insulating washer
- a Approximately 60°.

Figure A.7 — Stress by compression

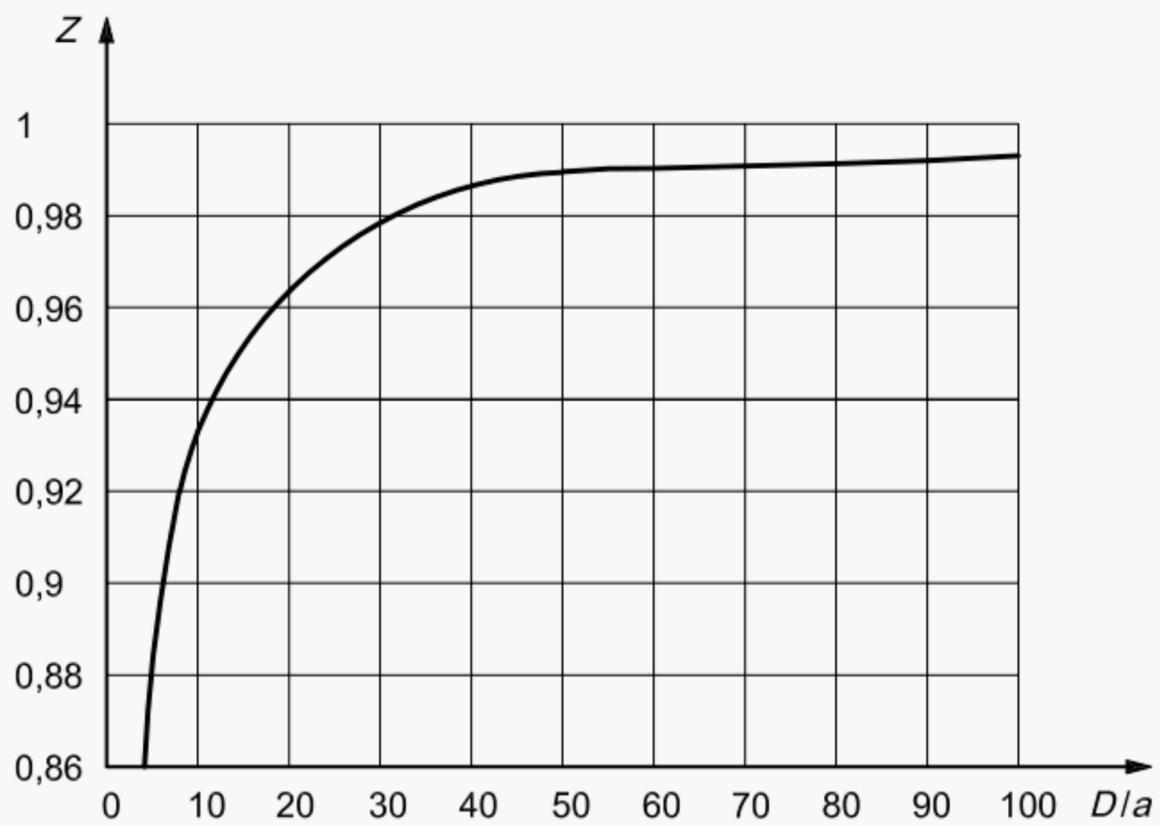


Figure A.8 — Correction factor z plotted against D/a

Annex B (normative)

New design type testing and production testing

B.1 New design type testing

NOTE The tests specified in this annex are suitable for use in the procedure for design type approval described in 6.2.2.5.4.9 of the UN model regulations for the transportation of dangerous goods ST/SG/AC.10/1/Rev.13.

B.1.1 New design type testing shall be carried out for each new design of cylinder.

A previously approved cylinder shall be considered to be of a new design type when any of the following conditions apply:

- a) it is manufactured in a different facility;
- b) it is manufactured by a different metal forming process (this includes the case when major process changes are made during the production period);
- c) it is manufactured using a different welding procedure;
- d) it is manufactured from an alloy of different specified composition limits from that used in the original new design test;
- e) it is given a different heat treatment that is outside the ranges defined in **4.2.3**;
- f) the base profile has changed (e.g. concave, convex, hemispherical) or there is a change in the designed base thickness;
- g) the overall length of the cylinder has increased by more than 50 % (cylinders with a length:diameter ratio less than 3:1 shall not be used as reference cylinders for any new design with this ratio greater than 3);
- h) the nominal outside diameter has changed by more than 1 %;
- i) an increase in test pressure which requires a change in design wall thickness (where a cylinder is to be used for a lower pressure duty than that for which design approval has been given, it shall not be deemed to be of a new design);
- j) the guaranteed minimum yield stress (R_e) and/or the guaranteed minimum tensile strength (R_g) have changed.

B.1.2 The applicant for new design type testing shall, for each new design of cylinder, submit the documentation necessary for the checks specified below and make available to the relevant authority a batch of at least 50 cylinders – which shall be guaranteed by the manufacturer to be representative of the production cylinders – from which the number of cylinders required for the tests referred to below will be taken, together with any additional information required. In particular, the applicant shall indicate the type of heat treatment and mechanical treatment, and the temperature and the duration of treatment under **4.2**. They shall provide cast analysis certificates for materials used in the manufacture of the cylinders. Every cylinder submitted to any test shall be identified to the batch.

B.1.3 In the course of the new design type testing process, it shall be verified that

- the calculation specified in **5.2** is correct;
- the thicknesses of the walls and, where applicable, the ends of two of the cylinders taken for tests meet the requirements of **5.2** and **5.3**, the measurements being taken on three transverse sections and over the whole of the longitudinal sections of the base and the head;
- the requirements of **4.1** (material) are conformed to;
- the requirements of **6.1** and **6.2** are conformed to;
- the geometrical requirements of **6.5** to **6.9** are conformed to for all the cylinders selected by the relevant authority;
- the internal and external surfaces of the cylinders are free of any defect which might make them unsafe to use (see **6.4**).

The following tests on the cylinders selected shall be witnessed:

- the radiography test as specified in **6.3**;
- the tests for resistance to corrosion on one cylinder, or two if the size of the cylinder does not allow it, intercrystalline corrosion and stress corrosion as specified in Annex A (it is not necessary to carry out these tests when only condition **B.1.1 f**) applies and/or when the nominal outside diameter has changed by less than 20 %);
- the tests specified in **7.2** (tensile and bend tests) on two cylinders; where the length of the cylinder is 1 500 mm or more, the tensile tests in a longitudinal direction and the bend tests shall be carried out on test pieces taken from the upper and lower regions of the shell;
- the tests specified in **7.3** (hydraulic burst test) on two cylinders;
- the tests specified in **7.4** (pressure cycling test) on two cylinders.

B.1.4 If the results of the checks are not satisfactory, proceed in accordance with **B.3**.

If the results of the test are satisfactory, a new design type testing certificate shall be issued. This new design type testing certificate may be in the form of a type approval certificate, a typical example of which is given in Annex D.

B.2 Production testing

B.2.1 For the purpose of production testing, the cylinder manufacturer shall provide the inspector with

- a) the type approval certificate;
- b) cast analysis certificates of the materials, including filler wire, used for the manufacture of the cylinders;
- c) certificate covering NDE (see **6.3**);
- d) means of identifying the cast of the material from which each cylinder was made – every cylinder shall be identifiable to the batch;
- e) a statement of the processes utilized as specified in **4.2** and the relevant documentation relating to the heat treatment and mechanical treatment (see Annex D);
- f) the serial numbers of the cylinders.

B.2.2 During production testing the inspector shall perform the following.

- a) Ascertain that the new design type testing certificate has been obtained and that the cylinders conform to it.
- b) Check the documents which give data concerning the materials.
- c) Check whether the technical requirements set out in Clauses **4**, **5** and **6** have been met and in particular check by an external and, if physically possible, internal, visual examination of the cylinders whether their construction and the checks carried out by the manufacturer in accordance with **6.2**, **6.4**, **6.5** and **6.6** are satisfactory; the visual examination shall cover at least 10 % of the cylinders manufactured. If one unacceptable defect is found (as described in Annex C), 100 % of the cylinders shall be inspected.
- d) Witness the tests specified in **7.2** and **7.3** on two cylinders that shall be taken at random from each batch of cylinders or part thereof that have been made from the same cast and have undergone the specified heat treatment in identical circumstances. One of the cylinders shall be subjected to the tests in **7.2** (mechanical tests) and the other to the tests prescribed in **7.3** (burst test).
- e) Assess the results of the checks on the homogeneity of the batch carried out on every cylinder by the manufacturer in accordance with **7.6** (homogeneity).
- f) Check the marking (see Clause **9**).
- g) Check the threads as prescribed in **6.5**.

B.2.3 The selection of specimens and all the tests shall be carried out in the presence and under the supervision of a representative of the inspector.

B.2.4 After all the tests specified have been carried out, all the cylinders in the batch shall be subjected to the hydraulic test specified in **7.5**.

B.2.5 If the results of the checks are satisfactory, the inspector shall verify that the cylinder is marked in accordance with ISO 13769, shall apply the conformity marks and shall issue a production testing certificate, a typical example of which is given in Annex D. If the results of the checks are not satisfactory, proceed in accordance with **B.3**

B.3 Failure to meet test requirements

B.3.1 The following procedure may be used both for new design type and production testing. 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 cylinder if possible. If the results of this test are satisfactory, the first test shall be ignored.
- b) If the test has been carried out in a satisfactory manner, the cause shall be identified or the batch shall be scrapped.
 - 1) If the failure is due to the heat treatment applied, the manufacturer may subject all the cylinders of the batch to further heat treatment(s).

The cylinders may be re-solution treated and artificially aged, or alternatively additional time at the ageing treatment temperature may be given.

- 2) If the failure is not due to the heat treatment applied, all the identified defective cylinders shall be scrapped or repaired by an approved method. The remaining cylinders shall then be considered as a new batch.

All the new design type or production tests shall be performed again. If any test or part of a test is unsatisfactory, all cylinders of the batch shall be scrapped. In both cases, this new batch shall be retested.

B.3.2 Cylinders that have been subject to reheat treatment may only be presented to the inspector once more for testing.

Annex C (normative)

Description, evaluation of manufacturing defects and conditions for rejection of welded aluminium-alloy gas cylinders at time of visual inspection

C.1 Introduction

Several types of defect can occur during the manufacture of a welded aluminium-alloy gas cylinder. Such defects can be mechanical or material. They can be due to the basic material used, the manufacturing process, heat treatment, manipulations, necking, machining, welding or marking operations and other occurrences during manufacture. The aim of this annex is to identify the manufacturing defects most commonly met and to provide rejection criteria to the inspectors who shall perform the visual inspection. Nevertheless, the inspector requires extensive field experience and good judgement to detect and to be able to evaluate and judge a defect at the time of the visual inspection.

C.2 General

C.2.1 It is essential to perform the visual internal and external inspections in good conditions. Appropriate sources of illumination with sufficient intensity shall be used, e.g. 50 lux.

The surface of the metal and particularly of the inner wall shall be completely clean, dry and free from oxidation products, corrosion and scale since these could obscure other more serious defects. Where necessary, the surface shall be cleaned under closely controlled conditions by suitable methods before further inspection.

After the cylinders have been welded and the threads have been cut, the internal weld seams and the internal neck area shall be examined by means of an introscope, dental mirror or other appliance.

C.2.2 Small defects may be removed by local dressing, grinding, machining, or other appropriate method. Great care shall be taken to avoid introducing new injurious defects. After such a repair, cylinders shall be re-examined and, if necessary, the wall thickness shall be rechecked.

C.3 Manufacturing defects

The most commonly found manufacturing defects and their definitions are listed in Table C.1. For welding-related defects, reference shall be made to ISO 10042, as identified in Table C.1

Rejection limits for repair or scrap (i.e. render unserviceable) are included in this Table C.1. These rejection limits are established following considerable field experience. They apply to all sizes and types of cylinders and service conditions. Nevertheless some customer specifications, some types of cylinder or some special service conditions may require more stringent criteria.

Table C.1 — Manufacturing defects

Defect	Description	Conditions for rejection	Repair or scrap
Bulge	Visible swelling of the wall	All cylinders with such a defect	Scrap
Dent (flat)	Visible depression in the wall that has neither penetrated nor removed metal (see Figure C.1)	— When the depth of the dent exceeds 2 % of the external diameter of the cylinder — When the diameter of the dent is less than 30 times its depth	Scrap Scrap
Cut, gouge, metallic or scale impression	Impression in the wall where metal has been removed or redistributed (due basically to the introduction of foreign bodies on the mandrel or matrix during extrusion or drawing operations)	Inside defect: if more than 5 % of the wall thickness, if with sharp notches or if the length exceeds 5 times the wall thickness of the cylinder	Scrap
		Outside defect: where the depth exceeds 5 % of the wall thickness	Repair if possible (see C.2.2)
Dent containing cut or gouge	Depression in the wall which contains a cut or gouge (see Figure C.2)	All cylinders with such defects	Scrap
Excessive grinding or machining	Local reduction of wall thickness by grinding or machining	When the wall thickness is reduced to below the minimum design thickness	Scrap
Ridge or rib	Longitudinal raised surface with sharp corners (see Figure C.3)	Inside defect: if the height exceeds 5 % of the wall thickness	Scrap
		Outside defect: where the height exceeds 5 % of the wall thickness	Repair if possible (see C.2.2)
Groove	Deep longitudinal notch (see Figure C.4)	Inside defect: if the depth exceeds 5 % of the wall thickness	Scrap
		Outside defect: when the depth exceeds 5 % of the wall thickness	Repair if possible (see C.2.2)
Lamination	Layering of material within cylinder wall and sometimes appearing as a discontinuity, crack, lap or bulge at the surface (see Figure C.5)	All cylinders with such a defect	Scrap
Blister	Small bulge on the wall containing a continuous layer of inclusions	Inside defect: all cylinders with such a defect	Scrap
		Outside defect: all cylinders with such a defect Not necessary to repair if clearly insignificant to cylinder performance	Repair if possible
Crack	Split or rift in the plate or in the weld metal (see ISO 10042)	All cylinders with such defects	Scrap

Table C.1 (continued)

Defect	Description	Conditions for rejection	Repair or scrap
Neck cracks	Appear as lines which run vertically down the thread and across the thread faces (not to be confused with tap marks or thread machining marks) (see Figure C.6)	All cylinders with such defects	Scrap
Welding-related defects	Refer to ISO 10042:2005, Table 1 for descriptions of weld defects	Apply level C of ISO 10042:2005	See ISO 10042
Folds in seamless body cylinders	Sharp visual groove along the length of the cylinder and usually in the inside of the dome area where the metal has flowed onto itself	Fold line in the thread area that enters and crosses more than one full thread.	Repair folds inside the dome area only if the fold line does not enter the threaded area (see 7.9) and the repair does not reduce the dome thickness below the minimum required
Internal threads damaged or out of tolerance	Threads damaged with dents, cuts, burrs or out of tolerance	<p>— When the design permits, threads may be re-tapped and re-checked by the appropriate thread gauge and carefully visually re-examined; the appropriate number of effective threads shall be achieved</p> <p>— If not repairable</p>	<p>Repair</p> <p>Scrap</p>
Pitting	Pitting due to bad acid cleaning or corrosion due to storage in bad conditions	<p>Inside defects: all cylinders with such defects</p> <p>Outside defects: all cylinders with such defects</p>	<p>Scrap</p> <p>Repair if possible (see C.2.2)</p>
Non-conformity with design drawing	Non-conformity with design drawing (e.g. neck or bottom form and dimensions, out of straightness, eccentricity, stability, lack of thickness)	All cylinders presenting such a defect	Repair if possible or scrap
Depressed bung	Damage to the bung which has altered the profile of the cylinder	All cylinders presenting such a defect	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 a defect	Scrap



Figure C.1 — Dent



Figure C.2 — Dent containing cut or gouge

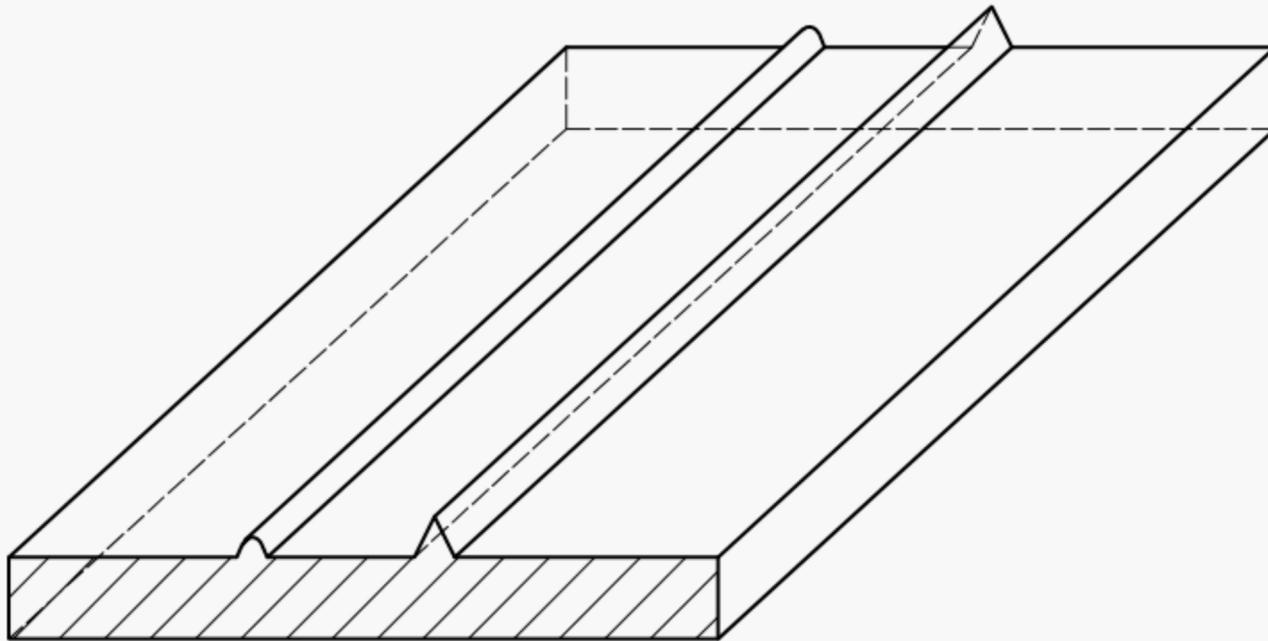


Figure C.3 — Ridges or ribs

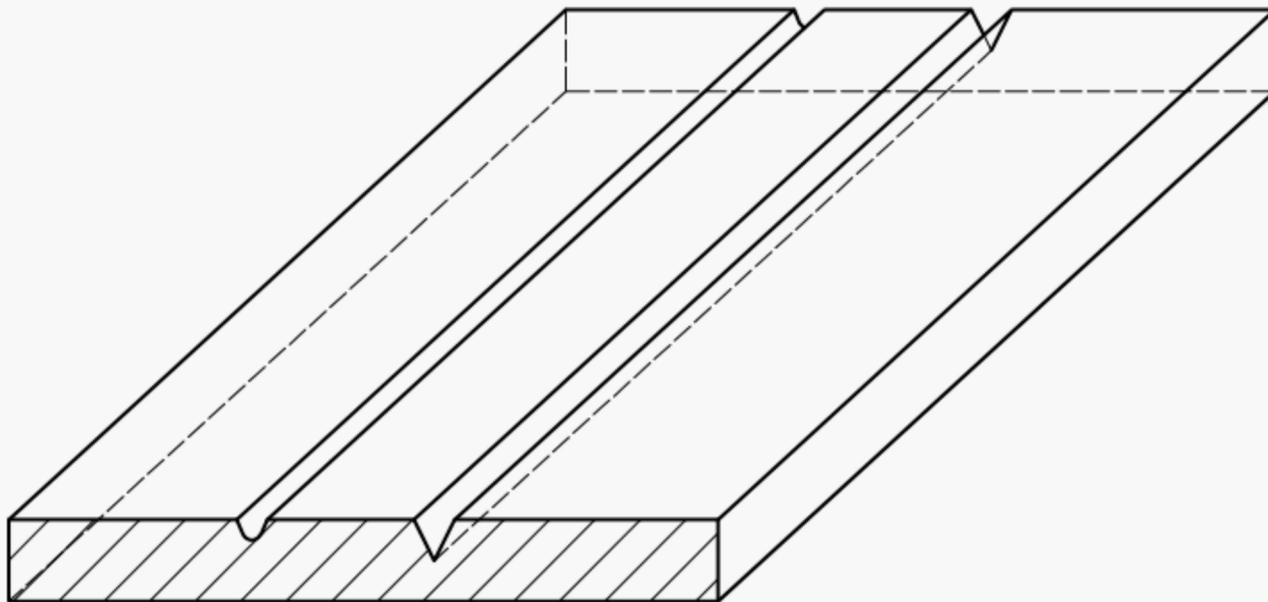


Figure C.4 — Grooves

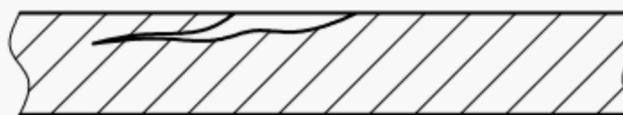


Figure C.5 — Lamination

Annex D
(informative)

Examples of new design type approval and production test certificates

D.1 Model new design type approval certificate

Issued by (*Relevant Authority*) on the basis of
.....
applying ISO 20703.....

concerning WELDED, ALUMINIUM-ALLOY GAS CYLINDERS

Approval No. Date

Type of cylinder ... (*Description of the family of cylinders which has received type approval*)

P_h D_{min} D_{max} a' b

L_{min} L_{max} V_{min} V_{max}

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

Type approval mark.....

Details of the results of the examination of the type for new design type approval and the main features of the type are attached.

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

Date Place

..... Signature

Comments for use with new design type approval certificate

- a) Results of new design type approval examination of the type with approval details should be attached.
- b) Main features of the type should be shown, in particular the following.
 - longitudinal cross-section of the type of cylinder which has received new design type approval, showing
 - the minimum and maximum nominal external diameter, D_{\min} and D_{\max} , with an indication of the design tolerances laid down by the manufacturer;
 - the guaranteed minimum thickness of the cylinder wall (a');
 - the guaranteed minimum thickness of the base (b) and the head with an indication of the design tolerances laid down by the manufacturer;
 - the minimum and maximum length(s), L_{\min} , L_{\max} , (L being the distance from the outside of the base of the shell to the top surface of the cylinder neck);
 - the water capacity or capacities, V_{\min} , V_{\max} ;
 - the hydraulic test pressure, p_h ;
 - the name of the manufacturer/No. of the drawing and date;
 - name of the type of cylinder;
 - the alloy in accordance with Clause 4 [nature/chemical composition/method of manufacture/heat treatment/guaranteed mechanical characteristics (tensile strength — yield stress)];
 - the welding procedure specifications.

D.2 Production testing certificate

Application of ISO 20703

Inspector

.....

Date

Type approval No.

Description of cylinders

.....

Production testing No.

Manufacturing batch No. to

Manufacturer (*Name and address*)

.....

.....

Country Mark

Owner (*Name and address*)

.....

.....

Customer (*Name and address*)

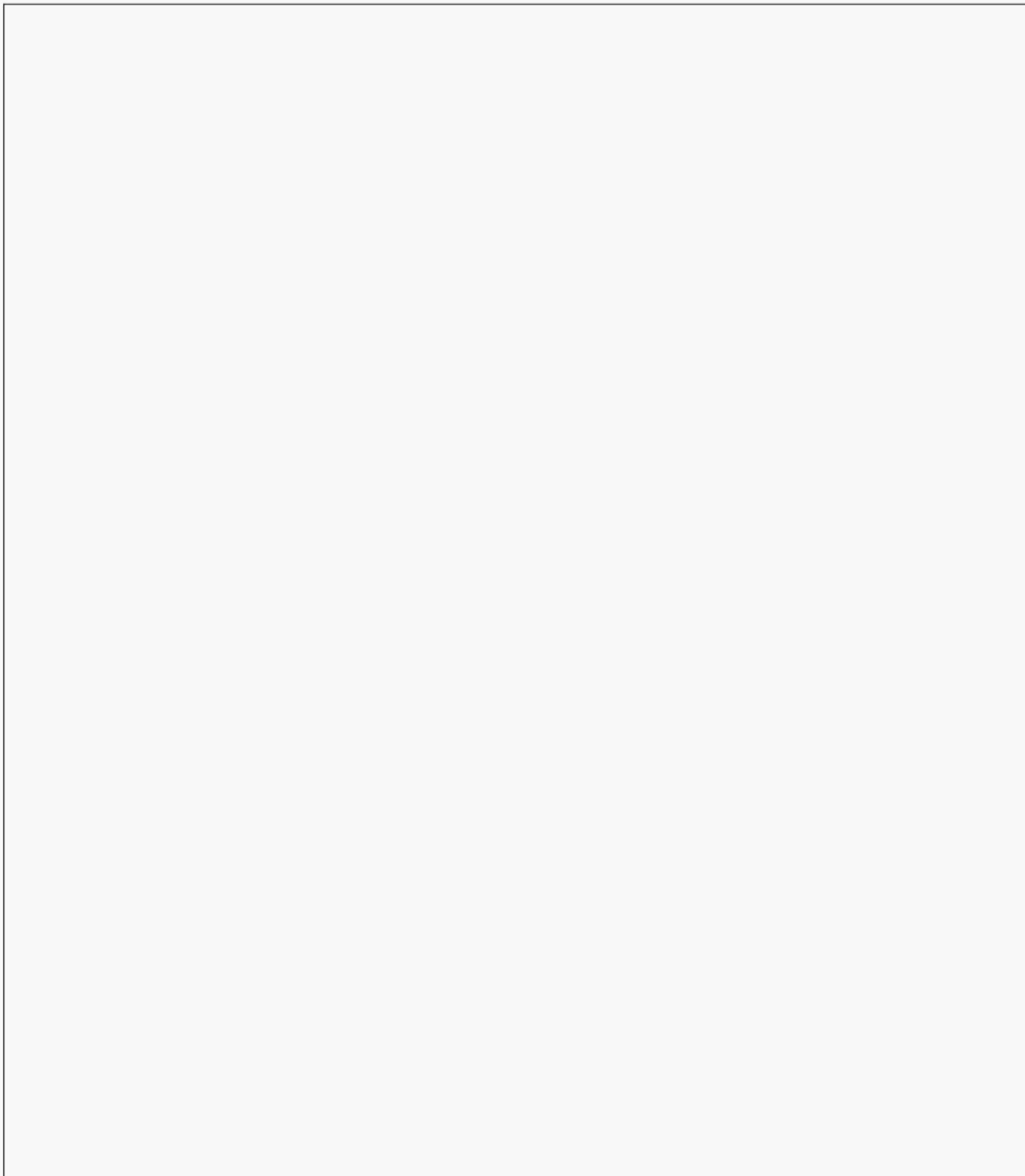
.....

Production tests

1 — Measurements of sample cylinders

Test No.	Batch consisting of No. to No.	Water capacity l	Mass empty kg	Minimum measured thickness	
				of the wall mm	of the base mm

2 — NDE results



3 — Mechanical tests carried out on sample cylinders

Test/ batch	Heat treatment NR	Tensile test				Bend test	Hydraulic burst test bar	Description of the fracture
		Test-piece in accordance with EN 10002-1	Yield stress R_{ea} MPa	Tensile strengt R_m MPa	Elongation A %			
Minimum values specified								

I, the undersigned hereby declare that I have checked that the requirements of **B.2** of ISO 20703: ____ have been carried out successfully.

Special remarks

General remarks

Certified on (date) Place

Signature of the inspector

On behalf of (Inspector)

Bibliography

- [1] ASTM E1221-88, *Standard Test Method for Determining Plane-Strain Crack Arrest Fracture Toughness K_{IA} of Ferritic Steels*, Paragraph 9.2.1
- [2] ASTM E399-90, *Standard Test Method for Linear-Elastic Plane-Strain Fracture Toughness K_{IC} of Metallic Materials*, Paragraph A5.5
- [3] ISO 10920:1997, *Gas cylinders — 25E taper thread for connection of valves to gas cylinders — Specification*
- [4] ISO 11191:1997, *Gas cylinders — 25E taper thread for connection of valves to gas cylinders — Inspection gauges*
- [5] ISO 11116-1:1999, *Gas cylinders — 17E taper thread for connection of valves to gas cylinders — Part 1: Specifications*
- [6] ISO 11116-2:1999, *Gas cylinders — 17E taper thread for connection of valves to gas cylinders — Part 2: Inspection gauges*
- [7] ST/SG/AC.10/1/Rev.13 *Recommendations on the Transport of Dangerous Goods Model Regulations, Thirteenth revised edition 2003* (updated to the latest edition at the time of the standard's publication as an FDIS).
- [8] ISO 7539-6, *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*
- [9] EN 10002-1, *Metallic materials — Tensile testing — Part 1: Method of testing at ambient temperature*

