
**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 %											
		Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Pb	Bi	Others	
												Each	Total
5052	A	—	—	—	—	2,2	0,15	—	—	—	—	—	—
		0,25	0,40	0,10	0,10	2,8	0,35	0,10	—	—	—	0,05	0,15
5154	A	—	—	—	—	3,1	0,15	—	—	—	—	—	—
		0,25	0,40	0,10	0,10	3,9	0,35	0,20	0,20	—	—	0,05	0,15
5083A	D	—	—	—	0,40	4,0	0,05	—	—	—	—	—	—
		0,40	0,40	0,10	1,0	4,9	0,25	0,25	0,15	—	—	0,05	0,15
6061A	D	0,40	—	0,15	—	0,8	0,04	—	—	—	—	—	—
		0,8	0,7	0,40	0,15	1,2	0,35	0,25	0,15	0,0030	0,0030	0,05	0,15
6063	C	0,2	—	—	—	0,4	—	—	—	—	—	—	—
		0,7	0,5	0,1	0,3	0,9	0,1	0,2	0,2	0,0030	—	0,05	0,15
6082	D	0,7	—	—	0,40	0,60	—	—	—	—	—	—	—
		1,3	0,50	0,10	1,0	1,2	0,25	0,20	0,10	0,0030	0,0030	0,05	0,15
6082	B	1,2	—	—	0,8	1,0	—	—	—	—	—	—	—
		1,6	0,5	0,1	1,0	1,4	0,1	0,2	0,2	0,0030	0,0030	0,05	0,15

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

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

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

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

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

- a) the thickness of the cylindrical wall, and
- b) 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

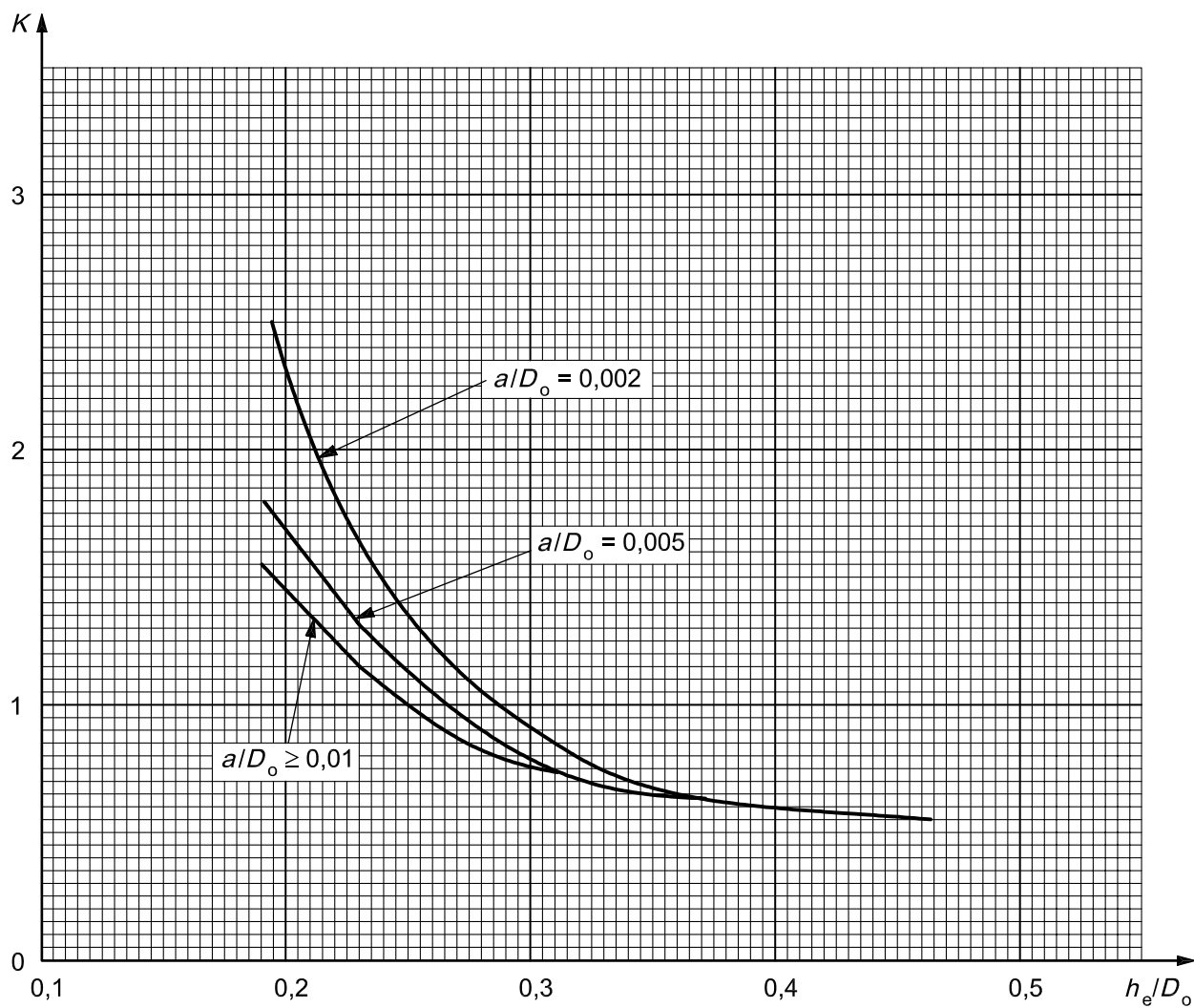
$$h_o = r_o' - \sqrt{\left\{ \left(r_o' - \frac{D_o}{2} \right) \times \left(r_o' + \frac{D_o}{2} - 2r_o \right) \right\}}$$

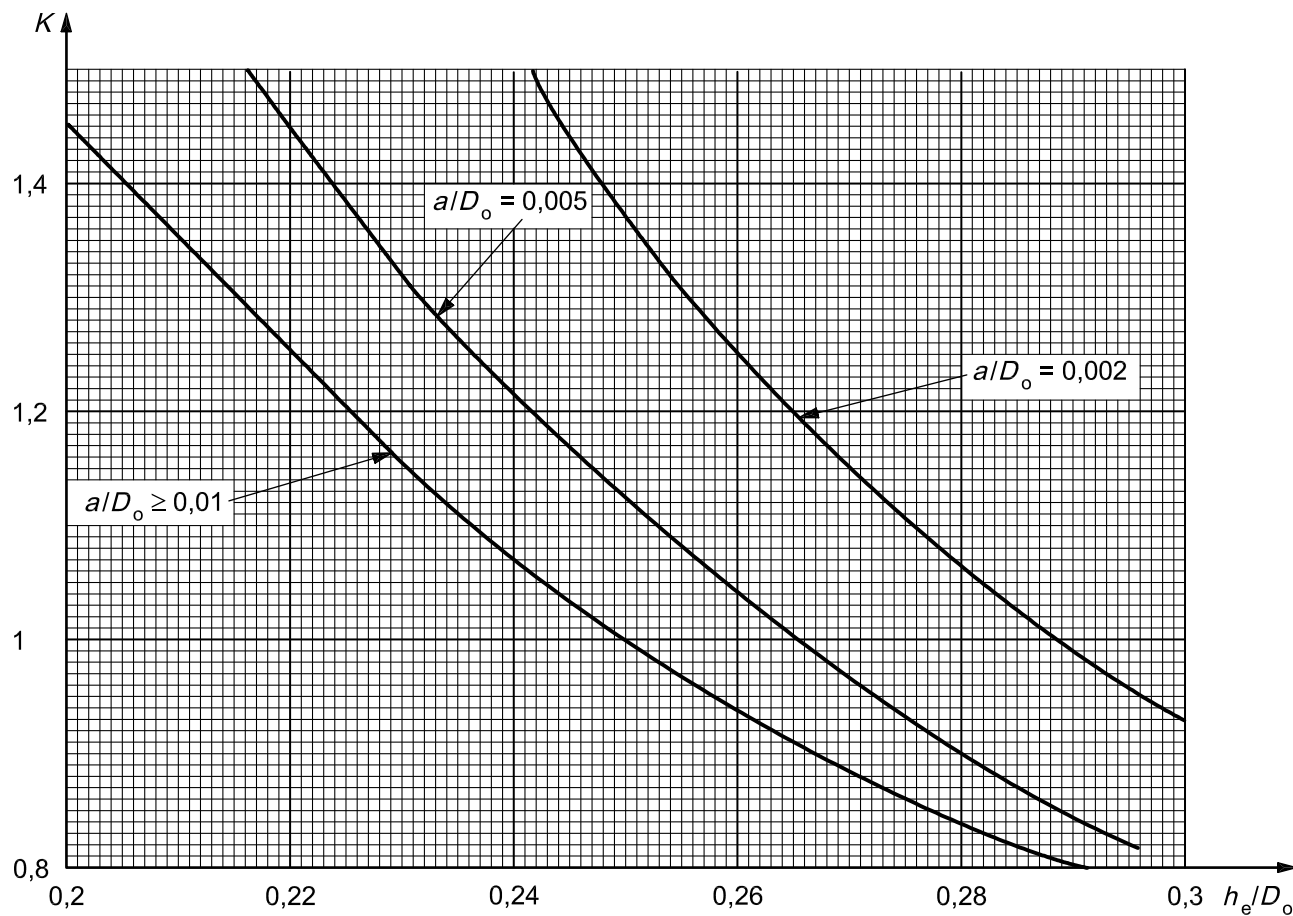
The wall thickness of the base shall not exceed 1,15 times the guaranteed minimum design thickness of the base (b). The external surface of the base of the selected cylinders may be machined if necessary.

5.3.2 Limitations of shape (see Figure 2)

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

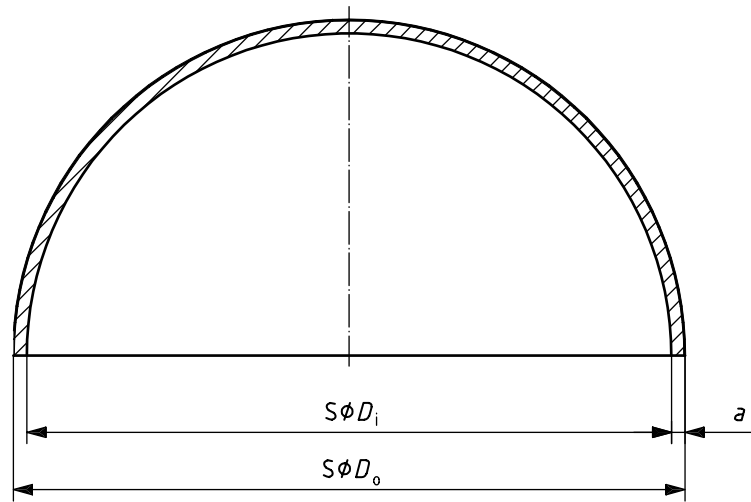
- a) For a torispherical end, r_i' shall be not greater than D_o .
- b) For a torispherical end, r_i shall be not less than $0,1D_i$ and not less than three times the actual thickness of the end as manufactured.
- c) For a semi-ellipsoidal end, the ratio h_o/D_o shall be not less than 0,192.
- d) For 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

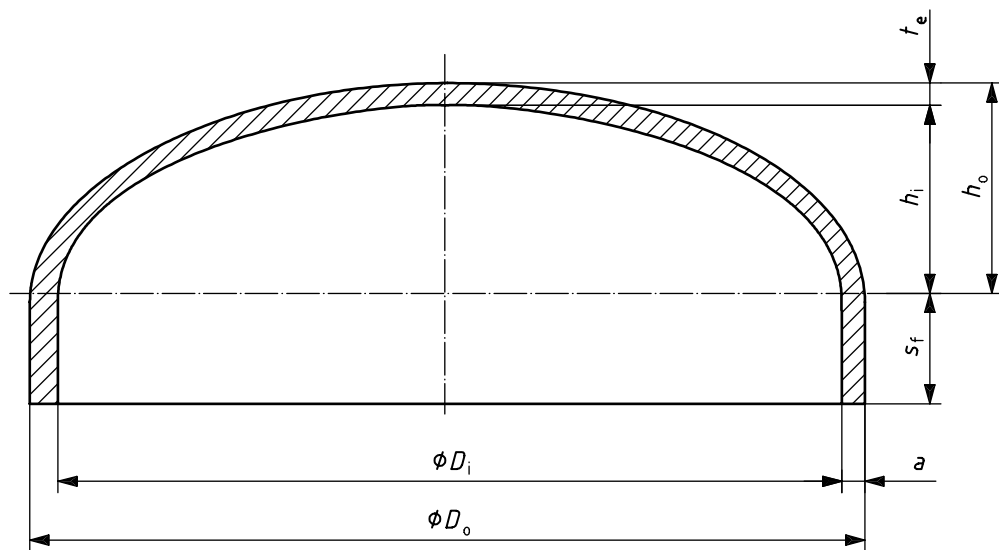


b) Shape factor K [enlargement of a)]

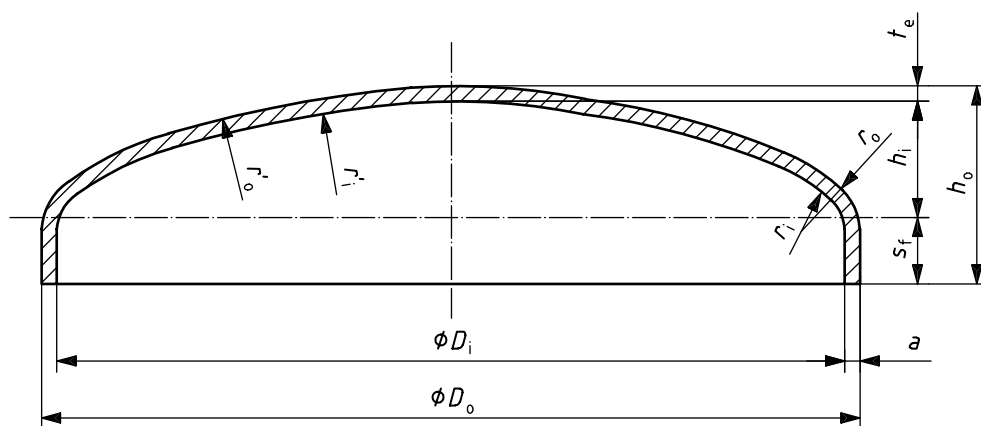
Figure 1 (continued)



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.