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Gas cylinders — Refillable welded aluminium alloy gas cylinders for greater than 60 bar test pressure - Design, construction and testing

Bouteilles à gaz — Bouteilles à gaz rechargeables en alliage d'aluminium soudées avec une pression d'essai supérieur à 60 bars — Conception, construction et essais

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Foreword

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ISO 26444 was prepared by Technical Committee ISO/TC 58, *Gas cylinders*, Subcommittee SC 3, *Gas cylinders design*.

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 with a test pressure greater than 60 bar. The specifications given are based on general knowledge of, and experience with, materials, design requirements, manufacturing processes and control during manufacture, of cylinders.

Gas cylinders — Refillable welded aluminium alloy gas cylinders for greater than 60 bar test pressure - 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, with a test pressure greater than 60 bar, of water capacities from 0,5 litre up to and including 150 litres 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 etc.

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 2107:1983, *Aluminium, magnesium and their alloys – Temper designations*

ISO 6892:1998, *Metallic materials – Tensile testing at ambient temperature*

ISO 7539-6:1995, *Corrosion of metals and alloys – Stress corrosion testing – Part 6: Preparation and use of pre-cracked specimens*

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 9956-4:1995, *Specification and approval of welding procedures for metallic materials – Part 4: Welding procedure tests for the arc welding of aluminium and its alloys*

ISO 10042:2005, *Arc-welded joints in aluminium and its weldable alloys; guidance on quality levels for imperfections*

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

ISO 11116-1, *Gas cylinders – 17E taper thread for connection of valves to gas cylinders – Part 1: Specifications*

ISO 11116-2, *Gas cylinders – 17E taper thread for connection of valves to gas cylinders – Part 2: Inspection gauges*

ISO 11117:1998, *Gas cylinders – Valve protection caps and valve guards for industrial and medical gas cylinders – Design, construction and tests*

ISO 11191:1997, *Gas cylinders – 25E taper thread for connection of valves to gas cylinders – Inspection gauges*

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

ISO 13769, *Gas cylinders – Stamp marking*

ISO 17636, *Non-destructive testing of welds – Radiographic testing of fusion-welded joints*

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 strength
value corresponding to the 0,2 % proof strength (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 200 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 duration of time

NOTE The lengths of the cylinders in the heat treatment batch may vary by up to ± 12 %.

3.1.6
design stress factor (F) (variable)
ratio of equivalent wall stress at test pressure (p_h) to guaranteed minimum yield strength (Reg)

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 after fracture, 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 and note below)

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 The 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_{eg} Minimum guaranteed value of the yield strength (see 3.1.1), in MPa, for the finished cylinder

R_{ea} Actual value of theyield strength, in MPa, as determined by the tensile test specified in 7.2.3 for the finished cylinder

R_{mg} Minimum guaranteed value of the tensile strength, in MPa, for the finished cylinder

R_{ma} Actual value of the tensile strength, in MPa, as determined by the tensile test specified in 7.2.3 for the finished cylinder

r_i Internal knuckle radius, in millimetres, of torispherical end (see Figure 2c))

1) 1 bar = 10^5 Pa = 10^5 N/m^2

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)

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 described in Annex A, and meet all other requirements of this International Standard, including Annex B.

4.1.2 Examples of the alloys most commonly used for the fabrication of gas cylinders are those 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 prototype 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 the 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 strength value of the O-tempered alloy (or the alloy annealed for complete re-crystallization before forming of cylinder, as defined in ISO 2107: 1983).

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 prototype 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.

Table 1 — Chemical composition of aluminium alloys

Type of alloy AA[1)] registered designation	Type 2), 3)		Chemical composition - weight %												
			Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Pb	Bi	Others Each	Others Total	Aluminium
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	
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	
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	
6061A	D	min.	0,40	-	0,15	-	0,8	0,04	-	-	-	-	-	-	Remainder
		max.	0,8	0,7	0,40	0,15	1,2	0,35	0,25	0,15	0,0030	0,0030	0,05	0,15	

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

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

3) Type D may be used for the body and the non pressure bearing part.

Table 1 — Chemical composition of aluminium alloys (cont.)

Type of alloy AA[1)] registered designation	Type 2), 3)		Chemical composition - weight %												
			Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Pb	Bi	Others		Aluminium
													Each	Total	
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	
6082	D	min	0,7	-	-	0,40	0,60	-	-	-	-	-	-	-	Remainder
		max	1,3	0,50	0,10	1,0	1,2	0,25	0,20	0,10	0,0030	0,0030	0,05	0,15	
6082	B	min	1,2	-	-	0,8	1,0	-	-	-	-	-	-	-	Remainder
		max	1,6	0,5	0,1	1,0	1,4	0,1	0,2	0,2	0,0030	0,0030	0,05	0,15	

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

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

3) Type D may be used for the body and the non pressure bearing part.

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 strength (R_{eg}) of the material to ensure elastic behaviour.

5.1.2 For calculation purposes the value of the yield strength (R_{eg}) is limited to a maximum of 0,9 R_{mg} for aluminium alloys.

5.1.3 The internal pressure upon which the calculation of wall thickness is based shall be the 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.

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:

$$a = \frac{D_o}{2}\left(1 - \sqrt{\frac{10\,FZR_{eg} - \sqrt{3}.p_h}{10\,FZ\,R_{eg}}}\right)$$

where the value of *F* is the lesser of $\frac{0,65}{(R_{eg}/R_{mg})}$ or 0,85; R_{eg}/R_{mg} shall be limited to 0,9.

the value of Z is dependent on the amount of non-destructive examination (NDE) and type of cylinder and shall be as specified in Table 2.

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

— for circumferential welds (including of bung or boss) 25 mm on each side of the weld overlap shall be examined;

— for longitudinal welds 100 mm beyond 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	0,95
	Welds spot checked	0,90
With longitudinal welds	100 % of welds NDE tested	0,5

The calculated minimum thickness shall also satisfy the equation:

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

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 prototype 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 ≥ 1,6.

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:

$$a = (p_h D_i)/(40FZR_e - 4{,}5p_h)$$

$$a = (p_h D_o)/(40FZR_e - 2{,}5p_h)$$

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

where 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, clauses 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; or

b) the value calculated from equation

$$t_e = aK$$

where K shall be as determined from Figure 1.