
**Gas cylinders — Design, construction
and testing of refillable seamless steel
gas cylinders and tubes —**

Part 4:

**Stainless steel cylinders with an R_m
value of less than 1 100 MPa**

*Bouteilles à gaz — Conception, construction et essais des bouteilles à
gaz et des tubes rechargeables en acier sans soudure —*

*Partie 4: Bouteilles en acier inoxydable avec une valeur R_m
inférieure à 1 100 MPa*

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Foreword

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

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

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

This second edition cancels and replaces the first edition (ISO 9809-4:2014), which has been technically revised. The main changes compared with the previous edition are as follows:

- update of [Clause 5](#);
- clarification of [Figure 3](#);
- clarification of [8.9](#);
- modification of [9.1](#), [9.2](#), [9.2.4](#) and [Annex A](#);
- new subclause [9.2.5](#) for parallel threads;
- new subclause [9.4](#) for cylinders ordered in small quantities.

A list of all parts in the ISO 9809 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document provides a specification for the design, manufacture, inspection and testing of a seamless stainless steel cylinder. The objective is to balance the design and economic efficiency against international acceptance and universal utility.

ISO 9809 (all parts) aims to eliminate the concern about climate, duplicate inspections and restrictions because of the lack of definitive International Standards.

This document has been written so that it is suitable to be referenced in the UN Model Regulations^[1].

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Gas cylinders — Design, construction and testing of refillable seamless steel gas cylinders and tubes —

Part 4:

Stainless steel cylinders with an R_m value of less than 1 100 MPa

1 Scope

This document specifies the minimum requirements for the materials, design, construction and workmanship, manufacturing processes, examinations and testing at time of manufacture for refillable, seamless, stainless steel gas cylinders with water capacities up to and including 150 l.

It is applicable to cylinders for compressed, liquefied and dissolved gases with a maximum actual tensile strength, R_{ma} , of less than 1 100 MPa.

NOTE If so desired, cylinders of water capacity between 150 l and 450 l can be manufactured to be in full conformance to this document.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 148-1, *Metallic materials — Charpy pendulum impact test — Part 1: Test method*

ISO 3651-2, *Determination of resistance to intergranular corrosion of stainless steels — Part 2: Ferritic, austenitic and ferritic-austenitic (duplex) stainless steels — Corrosion test in media containing sulfuric acid*

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

ISO 6508-1, *Metallic materials — Rockwell hardness test — Part 1: Test method*

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

ISO 9328-1, *Steel flat products for pressure purposes — Technical delivery conditions — Part 1: General requirements*

ISO 9329-4, *Seamless steel tubes for pressure purposes — Technical delivery conditions — Part 4: Austenitic stainless steels*

ISO 9712, *Non-destructive testing — Qualification and certification of NDT personnel*

ISO 10286, *Gas cylinders — Vocabulary*

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

ISO 13769, *Gas cylinders — Stamp marking*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 10286 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

3.1

batch

quantity of up to 200 cylinders, plus cylinders for destructive testing of the same nominal diameter, thickness, length and design made successively on the same equipment, from the same cast of steel, and subjected to the same heat treatment for the same duration of time

3.2

burst pressure

p_b
highest pressure reached in a cylinder during a burst test

3.3

cold working

process in which a cylinder is subjected to a pressure higher than the cylinder *test pressure* (3.11) to increase the *yield strength* (3.12) of the steel

3.4

cryoforming

process where the cylinder is subjected to a controlled low-temperature deformation treatment that results in a permanent increase in strength

3.5

design stress factor

F
ratio of the equivalent wall stress at *test pressure*, p_t , (3.11) to guaranteed minimum yield strength, R_{eg}

3.6

quenching

hardening heat treatment in which a cylinder, which has been heated to a uniform temperature above the upper critical point, A_{c3} , of the steel, is cooled rapidly on a suitable medium

3.7

reject

action to set aside a cylinder (Level 2 or Level 3) that is not allowed to go into service

3.8

rendered unserviceable

cylinder that has been treated in such a way as to render it impossible for use

Note 1 to entry: Examples for acceptable methods to render cylinders unserviceable can be found in ISO 18119. Any actions on cylinders rendered unserviceable are outside the scope of this document.

3.9

repair

action to return a rejected cylinder to a Level 1 condition

3.10

tempering

toughening heat treatment which follows *quenching* (3.6), in which the cylinder is heated to a uniform temperature below the critical point, A_{c1} , of the steel

3.11 test pressure

p_h
required pressure applied during a pressure test

Note 1 to entry: Test pressure is used for the cylinder wall thickness calculation.

3.12 yield strength

stress value corresponding to the 0,2 % proof stress or for austenitic steels in the solution-annealed condition, 1 % proof stress

3.13 working pressure

settled pressure of a compressed gas at a uniform reference temperature of 15 °C in a full gas cylinder

4 Symbols

A percentage elongation after fracture

a calculated minimum thickness, in millimetres, of the cylindrical shell

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

a_1 guaranteed minimum thickness, in millimetres, of a concave base at the knuckle (see [Figure 2](#))

a_2 guaranteed minimum thickness, in millimetres, at the centre of a concave base (see [Figure 2](#))

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

c_1 maximum permissible deviation, in millimetres, of burst profile for quenched and tempered cylinders (see [Figure 11](#))

c_2 maximum permissible deviation, in millimetres, of the burst profile for cryoformed or solution-annealed cylinders with less than 7,5 mm wall thickness (see [Figure 12](#))

D nominal outside diameter of the cylinder, in millimetres (see [Figure 1](#))

D_f diameter, in millimetres, of former (see [Figure 6](#))

F design stress factor (variable)

H outside height, in millimetres, of the domed part (convex head or base end) (see [Figure 1](#))

h outside depth (concave base end), in millimetres (see [Figure 2](#))

L_0 original gauge length, in millimetres, as defined in ISO 6892-1 (see [Figure 5](#))

l overall length of the cylinder, in millimetres (see [Figure 3](#))

n ratio of the diameter of the bend test former to the actual thickness of test piece, t

p_b measured burst pressure, in bar, above atmospheric pressure

NOTE 1 bar = 10^5 Pa = 0,1 MPa.

p_h hydraulic test pressure, in bar, above atmospheric pressure

p_y observed pressure when the cylinder starts yielding during the hydraulic burst test, in bar, above atmospheric pressure

r	inside knuckle radius, in millimetres (see Figures 1 and 2)
R_{ea}	actual value of the yield strength, in megapascals, as determined by the tensile test (see 10.2)
R_{eg}	minimum guaranteed value of the yield strength (see 7.1.1), in megapascals, for the finished cylinder
R_{ma}	actual value of the tensile strength, in megapascals, as determined by the tensile test (see 10.2)
R_{mg}	minimum guaranteed value of the tensile strength, in megapascals, for the finished cylinder
S_o	original cross-sectional area of the tensile test piece, in square millimetres, in accordance with ISO 6892-1
t	actual thickness of the test specimen, in millimetres
t_m	average cylinder wall thickness at the position of testing during the flattening test, in millimetres
u	ratio of the distance between the knife edges or platens in the flattening test to the average cylinder wall thickness at the position of the test
V	water capacity of the cylinder, in litres
w	width, in millimetres, of the tensile test piece (see Figure 5)

5 Inspection and testing

Assessment of conformity to this document shall take into account the applicable regulations of the countries of use.

To ensure that cylinders conform to this document, they shall be subject to inspection and testing in accordance with [Clauses 9](#), [10](#) and [11](#).

Tests and examinations performed to demonstrate compliance with this document shall be conducted using instruments calibrated before being put into service and thereafter according to an established programme.

6 Materials

6.1 General requirements

6.1.1 Materials for the manufacture of gas cylinders shall fall within one of the following categories:

- a) internationally recognized cylinder steels;
- b) nationally recognized cylinder steels;
- c) new cylinder steels resulting from technical progress.

For all categories, the relevant conditions specified in [6.2](#) and [6.3](#) shall be satisfied.

6.1.2 There is a risk of intergranular corrosion in austenitic and duplex stainless steels resulting from hot processing which can cause sensitization of the steel (e.g. chromium depletion in the grain boundary). Intergranular corrosion testing shall be carried out for such materials in accordance with [10.6](#).

6.1.3 The cylinder manufacturer shall establish the means to identify the cylinders with the cast of steel from which they are made.

6.1.4 Grades of steel used for the cylinder manufacture shall be compatible with the intended gas service, e.g. corrosive gases and embrittling gases (see ISO 11114-1).

6.1.5 Some grades of stainless steel can be susceptible to environmental stress corrosion cracking. Special precautions shall be taken in such cases, such as appropriate coating.

6.1.6 Some grades of stainless steel can be susceptible to phase transformation at low temperatures resulting in a brittle alloy. Special precautions shall be taken in such cases, i.e. not using the cylinder below the minimum acceptable temperature.

6.2 Controls on chemical composition

6.2.1 The following are the four broad categories of stainless steels:

- ferritic;
- martensitic;
- austenitic;
- austenitic/ferritic (duplex).

Recognized steels are listed in ISO 15510. Other grades of stainless steel can also be used provided that they fulfil all the requirements of this document.

6.2.2 The cylinder manufacturer shall obtain and make available certificates of cast (heat) analyses of the steels supplied for the construction of gas cylinders.

Should check analyses be required, they shall be carried out either on the specimens taken during the manufacture from the material in the form as supplied by the steel maker to the cylinder manufacturer, or from finished cylinders. In any check analysis, the maximum permissible deviation from the limits specified for the cast analyses shall conform to the values specified in ISO 9329-4.

6.3 Heat treatment

6.3.1 The cylinder manufacturer shall certify the heat treatment process applied to the finished cylinders.

6.3.2 The finished cylinders made from the ferritic or martensitic steel categories shall be quenched and tempered, except if they are cold worked (see [6.4](#)).

6.3.3 For the ferritic and martensitic steels, the heat treatment process shall achieve the required mechanical properties.

6.3.4 The actual temperature to which a type of steel is subjected to obtain a given tensile strength shall not deviate by more than ± 30 °C from the temperature specified by the cylinder manufacturer.

6.4 Cold working or cryoforming

Cold working or cryoforming is used to enhance the finished mechanical properties in certain stainless steel materials.

For cylinders that are subjected to cold working or to the cryoforming process, all the heat treatment requirements refer to the cylinder preform operations. Cold worked or cryoformed cylinders shall not be subjected to any subsequent heat treatment.

6.5 Failure to meet test requirements

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

- a) If there is evidence of a fault in carrying out a test, or an error of measurement, a further test shall be performed. If the result of this test is satisfactory, the first test shall be ignored.
- b) If the test has been carried out in a satisfactory manner, the cause of test failure shall be identified.
 - 1) If the failure is considered to be due to the heat treatment applied, the manufacturer may subject all the cylinders implicated by the failure to only one further heat treatment, e.g. if the failure is in a test representing the prototype or batch cylinders. Test failure shall require reheat treatment of all the represented cylinders prior to retesting. This reheat treatment shall consist of either re-tempering or complete reheat treatment. Whenever the cylinders are reheat-treated, the minimum guaranteed wall thickness shall be maintained. Only the relevant prototype or batch tests needed to prove the acceptability of the new batch shall be performed again. If one or more tests prove even partially unsatisfactory, all the cylinders of the batch shall be rejected.
 - 2) If the failure is due to a cause other than the heat treatment applied, all the cylinders with imperfections shall be either rejected or repaired such that the repaired cylinders pass the test(s) required for the repair. They shall then be reinstated as part of the original batch.

7 Design

7.1 General requirements

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

7.1.2 Cylinders shall be designed with one or two openings along the central cylinder axis only.

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

7.2 Design of cylindrical shell thickness

The guaranteed minimum thickness of the cylindrical shell, a' , shall not be less than the thickness calculated using [Formulae \(1\)](#) and [\(2\)](#), and additionally, [Formula \(3\)](#) shall be satisfied.

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

where the value of F is equal to 0,77.

The wall thickness shall also satisfy [Formula \(2\)](#):

$$a \geq \frac{D}{250} + 1 \quad (2)$$

with an absolute minimum of $a = 1,5$ mm.

The burst ratio shall be satisfied by test as given in [Formula \(3\)](#).

$$p_b/p_h \geq 1,6 \quad (3)$$

NOTE It is generally assumed that $p_h = 1,5$ times working pressure for compressed gases for cylinders designed and manufactured to conform with this document.

7.3 Design of convex ends (heads and bases)

7.3.1 When convex base ends (see [Figure 1](#)) are used, the thickness, b , at the centre of a convex end shall be not less than that required by the following criteria: where the inside knuckle radius, r , is not less than $0,075 D$, then:

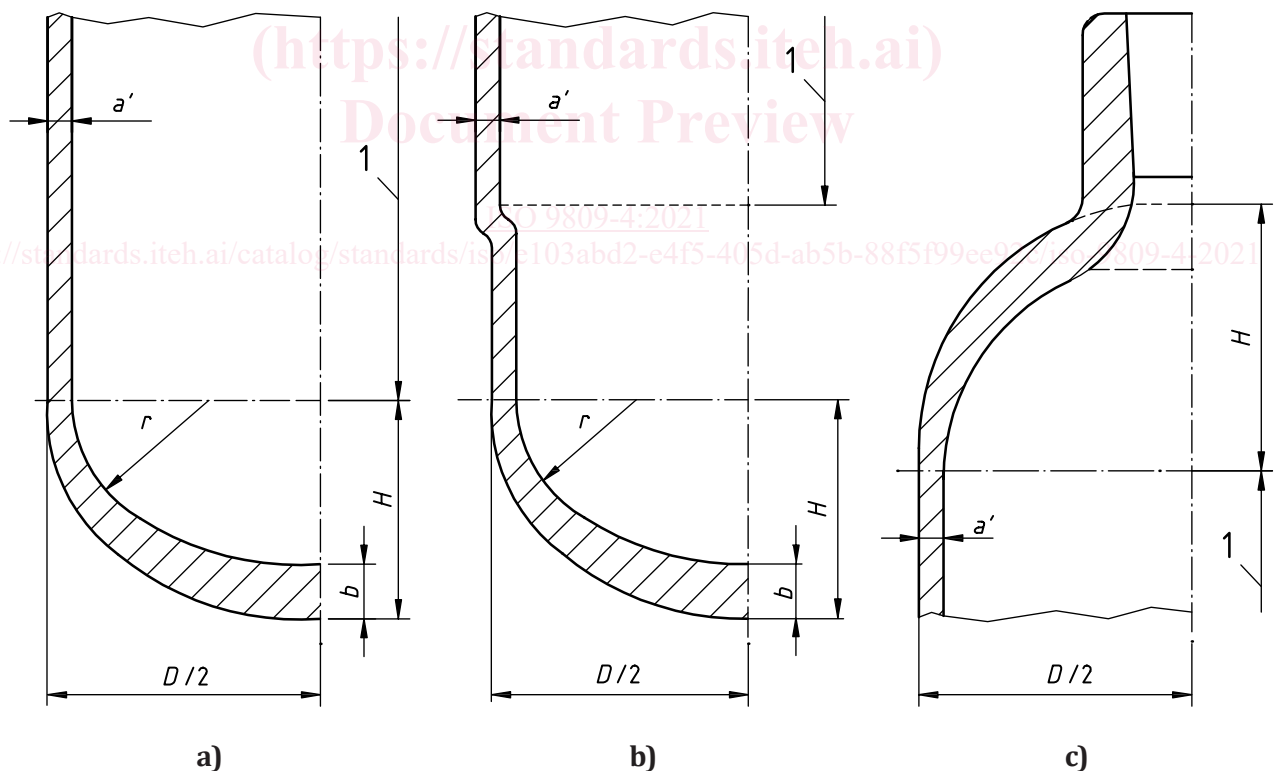
- $b \geq 1,5 a$ for $0,40 > H/D \geq 0,20$;
- $b \geq a$ for $H/D \geq 0,40$.

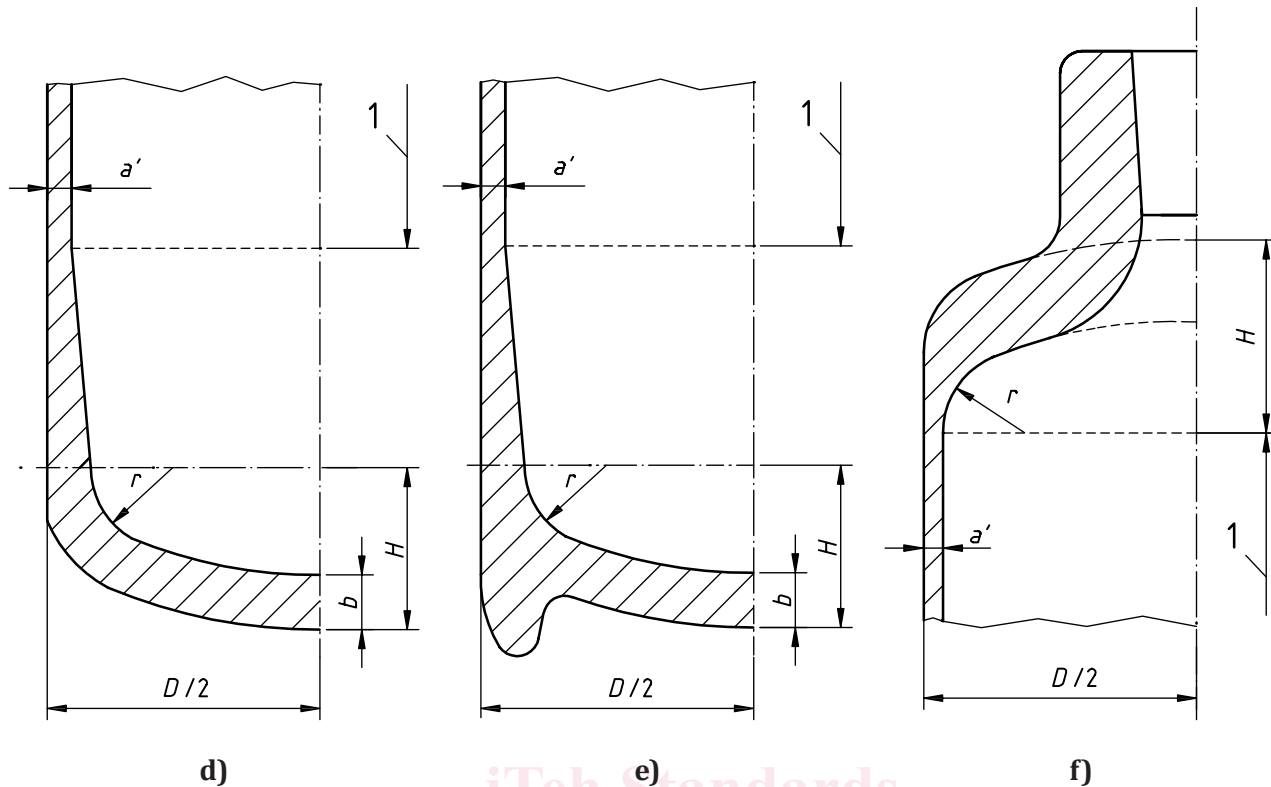
To obtain a satisfactory stress distribution in the region where the end joins the shell, any thickening of the end when required shall be gradual from the point of juncture, particularly at the base. For the application of this rule, the point of juncture between the shell and the end is defined by the horizontal lines indicating dimension H in [Figure 1](#).

Shape b) shall not be excluded from this requirement.

7.3.2 The cylinder manufacturer shall prove by the pressure cycling test detailed in [9.2.2](#) that the design is satisfactory.

The shapes shown in [Figure 1](#) are typical of convex heads and base ends. Shapes a), b), d) and e) are base ends, and shapes c) and f) are heads.





Key

1 cylindrical part

Figure 1 — Typical convex ends

7.4 Design of the concave base ends

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7.4.1 When concave base ends (see [Figure 2](#)) are used, the following design values are recommended:

- $a_1 \geq 2 a$;
- $a_2 \geq 2 a$;
- $h \geq 0,12 D$;
- $r \geq 0,075 D$.

The design drawing shall at least show values for a_1 , a_2 , h and r .

To obtain a satisfactory stress distribution, the thickness of the cylinder shall increase progressively in the transition region between the cylindrical part and the base.

7.4.2 The cylinder manufacturer shall in any case prove by the application of the pressure cycling test detailed in [9.2.2](#) that the design is satisfactory.