INTERNATIONAL STANDARD

ISO 9809-4

Second edition
2021-11

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].

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_h, (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, Ac_3, 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, Ac_1, 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_o 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.

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

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

The wall thickness shall also satisfy Formula (2):

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

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

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

$$p_b/p_h \geq 1{,}6 \qquad (3)$$

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 $0{,}40 > H/D \geq 0{,}20$;

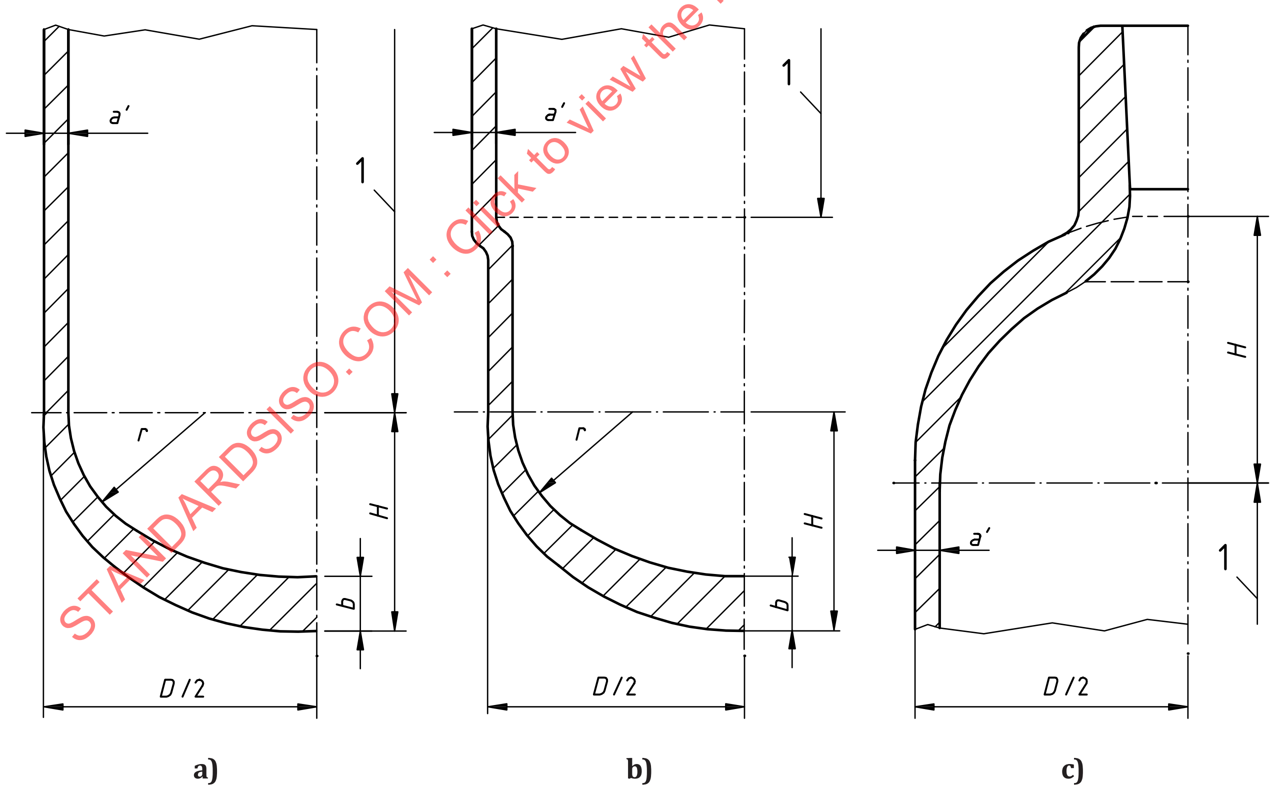
— $b \geq a$ for $H/D \geq 0{,}40$.

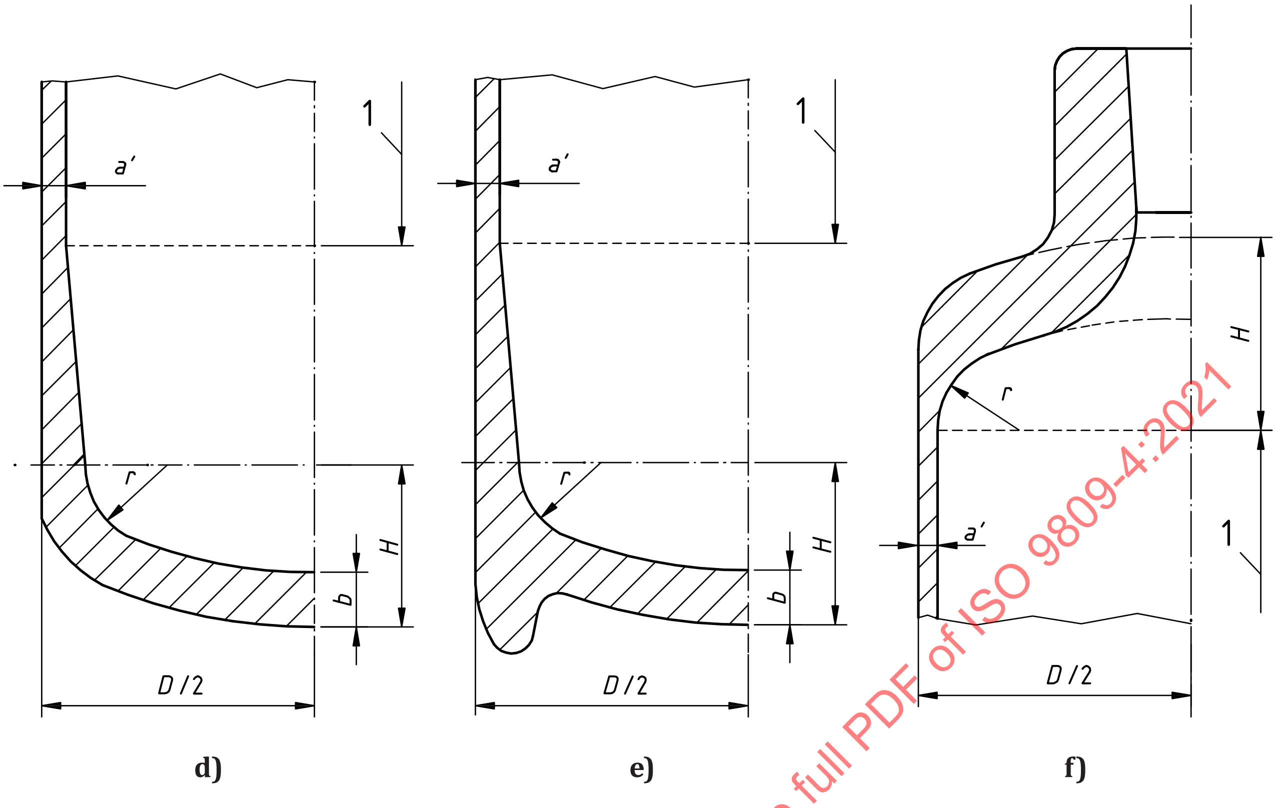
To obtain a satisfactory stress distribution in the region where the end joins the shell, any thickening of the end when required shall be gradual from the point of juncture, particularly at the base. For the application of this rule, the point of juncture between the shell and the end is defined by 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

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.

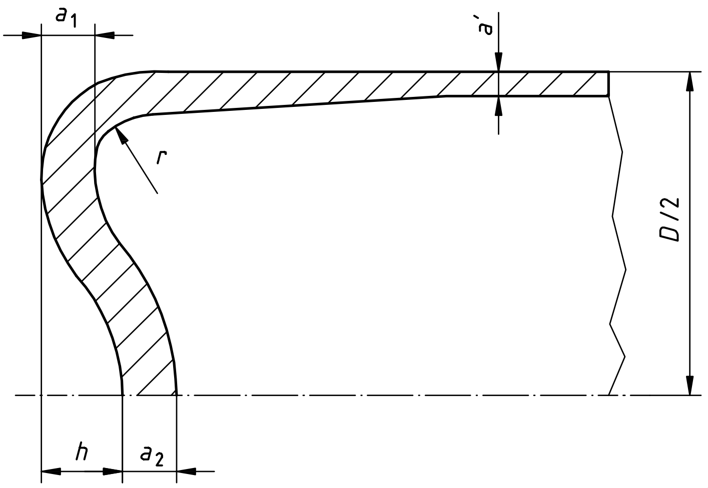


Figure 2 — Concave base ends

7.5 Neck design

7.5.1 The external diameter and thickness of the formed neck end of the cylinder shall be adequate for the torque applied in fitting the valve to the cylinder. The torque can vary according to the valve type, diameter of the thread, the form of the thread and the sealant used in the fitting of the valve.

NOTE For information on torques, see ISO 13341.

7.5.2 In establishing the minimum thickness, the thickness of the wall in the cylinder neck shall prevent permanent expansion of the neck during the initial and subsequent fittings of the valve into the cylinder without support of an attachment. The external diameter and thickness of the formed neck end of the cylinder shall not be damaged (no permanent expansion or crack) by the application of the maximum torque required to fit the valve to the cylinder (see ISO 13341) and the stresses when the cylinder is subjected to its test pressure. In specific cases (e.g. very thin-walled cylinders) where these stresses cannot be supported by the neck itself, the neck maybe designed to require reinforcement, such as a neck ring or shrunk on collar, provided the reinforcement material and dimensions are clearly specified by the manufacturer and this configuration is part of the type approval procedure (see 9.2.4 and 9.2.5).

7.6 Foot rings

When a foot ring is provided, it shall be made of material compatible with that of the cylinder. The shape should preferably be cylindrical and shall give the cylinder stability. The foot ring shall be secured to the cylinder by a method other than welding, brazing or soldering. Any gaps which can form water traps shall be sealed by a method other than welding, brazing or soldering.

7.7 Neck rings

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

The axial load to remove the neck ring shall be greater than 10 times the weight of the empty cylinder but not less than 1 000 N, and that the torque to turn the neck ring is greater than 100 Nm.

7.8 Design drawing

A fully dimensioned drawing shall be prepared which includes the specification of the material and details relevant to the design of the permanent fittings. Dimensions of non-safety related fittings can be agreed between the customer and manufacturer and need not be shown on the design drawing.

8 Construction and workmanship

8.1 General

The cylinder shall be produced by:

a) forging or drop forging from a solid ingot or billet;

b) manufacturing from seamless tube;

c) pressing from a flat plate;

d) cold working or cryoforming preform.

Metal shall not be added in the process of closure of the end. Manufacturing defects shall not be corrected by plugging of bases (e.g. addition of metal by welding).

8.2 Wall thickness

During production, each cylinder or semi-finished shell shall be examined for thickness. The wall thickness at any point shall be not less than the minimum thickness specified.

8.3 Surface imperfections

The internal and external surfaces of the finished cylinder shall be free from imperfections which could adversely affect the safe working of the cylinder. For examples of imperfections and assistance on their evaluation, see Annex A.

8.4 Ultrasonic examination

8.4.1 After completion of the final heat treatment and cold working and after the final cylindrical wall thickness has been achieved, each cylinder shall be ultrasonically examined for internal, external and sub-surface imperfections in accordance with Annex B.

8.4.2 In addition to the ultrasonic examination as specified in 8.4.1, the cylindrical area to be closed (which creates the shoulder and in case of cylinders made from tube, also the base) shall be ultrasonically examined prior to the forming process to detect any defects that after closure could be positioned in the cylinder ends.

In case of cylinders produced from tubes (provided that the thickness of the tube is unaltered), this additional test is not required if the tube is 100 % ultrasonic tested before closure of the ends in accordance with Annex B.

The test shall be performed as close as possible to the open end of the shell.

The untested area shall extend to a length of not more than 40 mm from the open end of the shell.

In both 8.4.1 and 8.4.2, it is not required to perform the ultrasonic examination for small cylinders with a cylindrical length of less than 200 mm or where the product of $p_h \times V < 600$ bar. l (for $R_{ma} \geq 650$ MPa) or $p_h \times V < 1\ 200$ bar. l (for $R_{ma} < 650$ MPa).

8.5 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 diameters.

For cold stretch and cryoformed cylinders, higher values are acceptable provided they are validated by the pressure cycling test and the maximum shall be specified on the approved design drawing.

8.6 Mean diameter

The mean external diameter of the cylindrical part outside the transition zones on a cross-section shall not deviate by more than ±1 % from the nominal design diameter.

For cold stretch and cryoformed cylinders, higher values are acceptable provided they are validated by the pressure cycling test and the maximum shall be specified on the approved design drawing.

8.7 Straightness

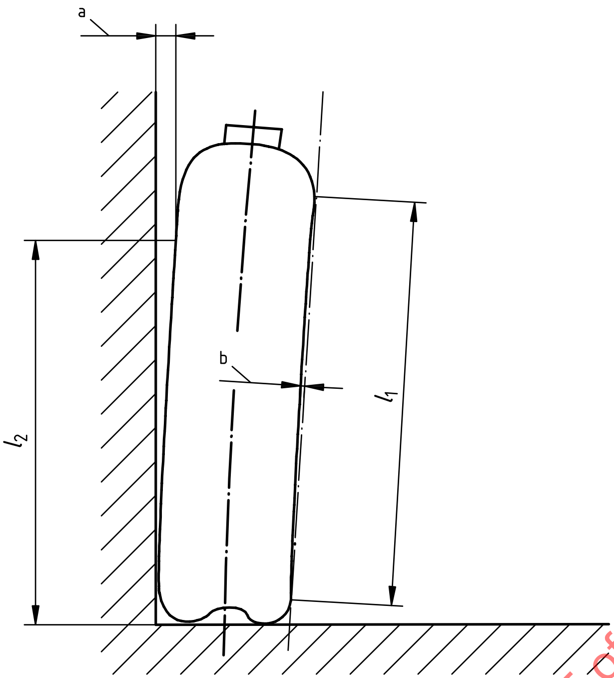
The maximum deviation, *b*, of the cylindrical part of the shell from a straight line shall not exceed 3 mm per metre in length (see Figure 3).

For cold stretch and cryoformed cylinders, higher values can be used provided that they are acceptable for the intended application.

8.8 Verticality and stability

For a cylinder designed to stand on its base, the deviation, *a*, from vertical shall not exceed 10 mm per metre in length (l_2) (see Figure 3). The outer diameter of the surface in contact with the ground is recommended to be greater than 75 % of the nominal outside diameter.

For cold stretch and cryoformed cylinders, higher values for deviation from vertical can be used provided that they are acceptable for the intended application.



Key

a maximum 0,01 × l_2 (see 8.8)

b maximum 0,003 × l_1 (see 8.7)

Figure 3 — Deviation of the cylindrical part of the shell from a straight line and from vertical

8.9 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 torqueing 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 Where the neck thread is specified to be in accordance with ISO 11363-1, the corresponding gauges are specified in ISO 11363-2.

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.

9 Type approval procedure

9.1 General requirements

A technical specification of each new design of cylinder or cylinder family as defined in f), including design drawing, design calculations, steel details, manufacturing process and heat treatment details, shall be submitted by the manufacturer to the inspector. The type approval tests detailed in 9.2 shall be carried out on each new design under the supervision of the inspector.

A cylinder shall be considered to be of a new design, compared with an existing approved design, when at least one of the following applies:

a) it is manufactured in a different factory;

b) it is manufactured by a different process (see 8.1); this includes the case when major process changes are made during the production period, e.g. end forging to spinning, change in heat treatment process;

c) it is manufactured from a steel of different specified chemical composition range from that defined in 6.2;

d) it is given a different heat treatment beyond the limits stipulated in 6.3 and 6.4;

e) the base or the base profile has changed, e.g. concave, convex, hemispherical, or the base thickness/cylinder diameter ratio has changed;

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

g) the nominal outside diameter has changed;

h) the guaranteed minimum thickness has changed;

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

NOTE When the test pressure has decreased, a revision of the type approval certificate can be needed.

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

If the diameter of the internal thread has increased by less than 50 % then:

— in case of tapered threads, the torque test shall be performed (see 9.2.4);

— in case of parallel threads, the calculation of the shear strength shall be performed (see 9.2.5).

If the diameter of the internal thread has increased by 50 % or more, the pressure cycling test on two cylinders shall also be performed (see 9.2.2).

In both cases, the new diameter shall be reported in the revised type approval certificate.

9.2 Prototype test

9.2.1 General requirements

A minimum of 30 cylinders which are guaranteed by the manufacturer to be representative of the new design shall be made available for the prototype testing. However, if for special applications the total number of cylinders required is less than 30, see 9.4.

In the course of the type approval process, the inspector shall select the necessary cylinders for testing and:

a) verify that:

  — the design conforms to the requirements of Clause 7;

  — requirements of 7.3 to 7.6 are met, the measurements being taken on at least three transverse sections of the cylindrical part and on a longitudinal section of the base and head;

  — the requirements of Clause 6 are conformed to;

  — the requirements of 7.6, 7.7, 7.8, and 8.5 to 8.9 inclusive are conformed to for all cylinders selected for inspection;

— the internal and external surfaces of the cylinders are free of any defect which should make them unsafe to use (for examples, see Annex A);

b) supervise the following tests on the cylinders selected:

— the tests specified in 10.1.2 a) (hydraulic burst test) on two cylinders, the cylinders bearing representative stamp markings;

— the tests specified in 10.1.2 b) (mechanical testing) on two cylinders, the test pieces being identifiable with the batch;

NOTE For cylinders made from austenitic stainless steel, see 10.4.

— the tests specified in 9.2.3 (base check) on the two cylinders selected for mechanical testing;

— an intergranular corrosion test in accordance with 10.6 for cylinders made from austenitic and duplex steels;

— the tests specified in 9.2.2 (pressure cycling test) on three cylinders, the cylinders bearing representative stamp markings;

— the neck threads conform to the geometrical requirements for all inspected cylinders;

— the tests specified in 9.2.4 or 9.2.5 on one cylinder, which is traceable with the batch.

9.2.2 Pressure cycling test

This test shall be carried out on cylinders bearing representative markings with a non-corrosive liquid, subjecting the cylinders 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.

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

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

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

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

After the test, the cylinder bases shall be sectioned to measure the thickness and to ensure that this thickness is sufficiently close to the minimum thickness prescribed in the design and shall be within the usual production tolerances. In no case shall the actual base thickness a_1 (for concave base) or b (for convex base) exceed the minimum value(s) specified on the drawings by more than 15 %. If the specific type approval procedure for small quantities is followed (see 9.4), the cylinder base shall be sectioned after the burst test if the pressure cycling test and the burst test are performed on the same cylinder.

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

9.2.3 Base check

A meridian section shall be made in the base centre of the cylinder and one of the surfaces, thus obtained, polished for examination under a magnification of between ×5 and ×10.

The cylinder shall be regarded as defective if the presence of cracks is detected. It shall also be regarded as defective if the dimensions of any pores or inclusions present reach values considered to pose a threat to safety.

For cylinders manufactured from tube, the base section shall be etched after the initial visual examination of the polished surface, to verify the absence of a plug. In no case shall the sound thickness (i.e. the thickness with no imperfections) in the base centre be less than the minimum specified thickness (see 7.4.1).

9.2.4 Torque test for taper thread only

9.2.4.1 Procedure

The body of the cylinder shall be held in such a manner as to prevent it from rotating. The cylinder shall be fitted with a valve or a plug and tightened to 1,5 times the maximum torque specified in ISO 13341 for the relevant material or as recommended by the manufacturer where not covered by ISO 13341. If a neck ring is part of the cylinder design, it shall be attached to the cylinder during torque test.

The parameters that shall be monitored and recorded are:

a) valve or plug material;

b) valving procedure;

c) applied torque;

d) diameter of internal tapered thread at upper end.

9.2.4.2 Acceptance criteria

The cylinder neck and threads shall remain within the gauge tolerances.

9.2.5 Shear stress calculation for parallel threads

9.2.5.1 Procedure

The bigger diameter of the parallel threads shall have a tight fit and a calculated shear strength of at least 10 times the shear stress at the test pressure of the cylinder.

NOTE An example of the shear stress calculation can be found in Annex E, which is based on US-FED-STD-H28/2.

The parameters that shall be recorded are:

a) type of thread;

b) calculated shear stress level.

9.2.5.2 Acceptance criteria

The calculated shear strength shall be at least 10 times the shear stress at test pressure.

9.3 Type approval certificate

If the results of the verifications and tests according to 9.2 are satisfactory, the inspector shall issue a type approval certificate. Annex C provides an example of a type approval certificate. Other formats with at least the same content are also acceptable.

9.4 Specific type approval/production tests for cylinders ordered in small quantities

For cylinders ordered in small quantities, the type approval is limited to the given order. For such orders, Clause 10 can be ignored. The inspector shall select two cylinders on each order for testing and:

a) verify that:

— the design conforms to the requirements of Clause 7;

— the thicknesses of the walls and ends on two cylinders (those taken for mechanical testing) meet the requirements of 7.3 to 7.6, the measurements being taken on at least three transverse sections of the cylindrical part and on a longitudinal section of the base and head;

— the requirements of Clause 6 are conformed to;

— the requirements of 7.6, 7.7, 7.8, and 8.5 to 8.9 inclusive are conformed to for all cylinders selected for inspection;

— the internal and external surfaces of the cylinders are free of any defect which should make them unsafe to use (for examples, see Annex A);

b) supervise the following tests:

— one cylinder shall be subjected to the pressure cycling test (see procedure and acceptance criteria in 9.2.2), then it shall be subjected to hydraulic burst tests (see procedure and acceptance criteria in 10.5);

NOTE The pressure cycling test and the hydraulic burst test can be performed on two different cylinders.

— one cylinder shall be subjected to mechanical tests specified in 10.2, 10.3 and 10.4, and on the same cylinder apply the torque test (see procedure and acceptance criteria in 9.2.4) or shear stress calculation as applicable (see procedure and acceptance criteria in 9.2.5).

10 Batch tests

10.1 General requirements

10.1.1 All tests for checking the quality of the gas cylinder shall be carried out at the completion of the cylinder manufacture, i.e. at any stage after the heat treatment.

For the purposes of the batch testing, the manufacturer shall provide the inspector with:

— the type approval certificate;

— the certificates stating the cast analysis of the steel supplied for the construction of the cylinders;

— evidence that appropriate heat treatment has been performed;

— the certificates showing the ultrasonic examination results;

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

— confirmation that threads have been checked in accordance with gauging requirements. The gauges to be used shall be specified (e.g. ISO 11363-2).

10.1.2 During the batch testing, the inspector shall undertake the following.

— Ascertain that the type approval certificate has been obtained and that the cylinders conform to it.

— Check whether the requirements given in Clauses 6, 7 and 8 have been met and, in particular, check by an external and internal visual examination of the cylinders whether their construction is satisfactory. The inspector shall verify that the requirements of 7.7, 7.8, and 8.2 to 8.9 have been fulfilled by the manufacturer. The visual examination shall cover at least 10 % of the cylinders submitted. However, if an unacceptable imperfection is found (as specified in Annex A), 100 % of cylinders shall be visually inspected.

— Select the necessary cylinders per batch for destructive testing and carry out the tests specified in 10.1.2 a) (hydraulic burst tests) and 10.1.2 b) (mechanical testing). Where alternative tests are permitted, the purchaser and the manufacturer shall agree which tests are to be carried out. Where cold working or cryoforming causes inhomogeneity of mechanical properties within the cylinder, sufficient sets of test pieces shall be taken in accordance with Figure 4 to prove the design. Where alternative tests are permitted, the purchaser and the manufacturer shall agree on which tests are to be carried out.

— Check whether the information supplied by the manufacturer referred to in 10.1.1 is correct. Random checks shall be carried out.

— Assess the results of the hardness testing specified in 11.3.

The following tests shall be carried out on each batch of cylinders.

a) On one cylinder, one hydraulic burst test (see 10.5).

b) On a further cylinder:

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

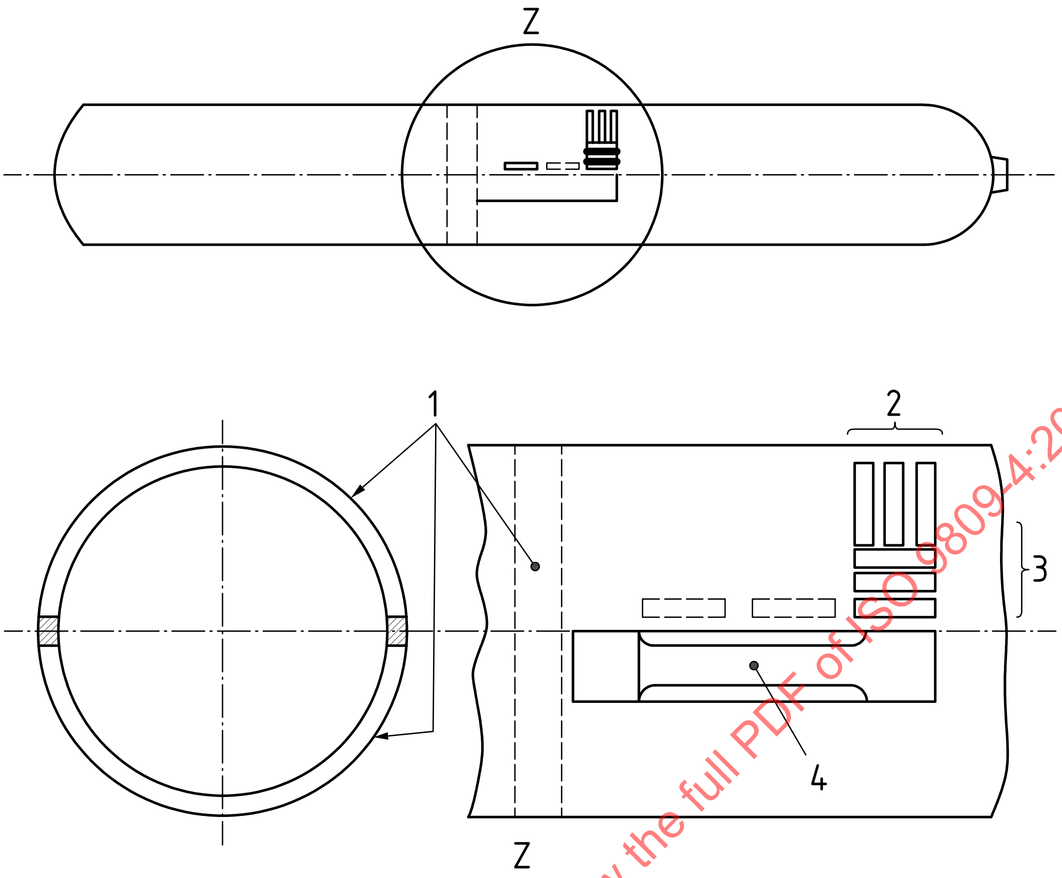
  — either two bend tests (see 10.3.1) in a circumferential direction, one flattening test (see 10.3.2), or one ring flattening test (see 10.3.3): this can be done on the same cylinders as those taken for mechanical testing.;

  — when necessary and when the thickness of the cylinder permits the machining of a test piece at least 3 mm thick, three impact tests in the transverse or longitudinal direction as required in 10.4;

  — for cylinders made from austenitic and duplex steels, an intergranular corrosion test in accordance with 10.6;

  — for cylinders made from continuously cast material, a base check in accordance with the requirements of 9.2.3 shall be carried out.

NOTE For the location of test pieces, see Figure 4.



Key

1 bend test pieces or flattening ring test pieces

2 transverse impact test pieces

3 longitudinal impact test piece (alternative positions shown dashed)

4 tensile test pieces

Figure 4 — Typical location of the test pieces

10.2 Tensile test

10.2.1 A tensile test shall be carried out on the material taken from the cylindrical part of the cylinder by adopting either of the following procedures.

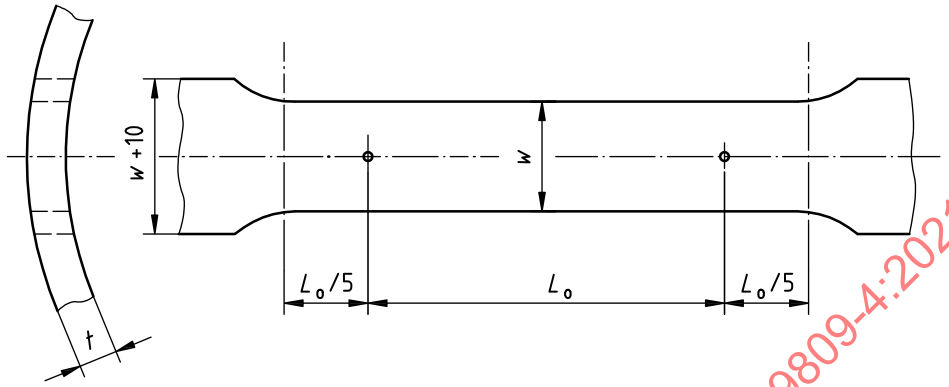
a) The rectangular specimens shall be prepared in accordance with Figure 5 and with a gauge length $L_o = 5{,}65\sqrt{S_o}$. The two faces of the test piece, representing the inside and outside surfaces of the cylinder, shall not be machined. The minimum percentage elongation values shall be those given for the material in ISO 9328-1, when in the same condition. The elongation values for other material grades not covered by ISO 9328-1 shall be agreed between the cylinder manufacturer and the relevant authority. However, the elongation after fracture (A) measured shall in no case be less than 14 %.

b) The machined round specimens shall be prepared having the maximum diameter practicable, the elongation, A, measured on a gauge length of five times the specimen diameter being no less than those specified in 10.2.1 a) plus 2 %, but in no case less than 16 %.

It is recommended that the machined round specimens are not used for wall thickness less than 3 mm.

10.2.2 The tensile test shall be carried out in accordance with ISO 6892-1.

NOTE Attention is drawn to the method of measurement of elongation described in ISO 6892-1, particularly in cases where the tensile test piece is tapered, resulting in a point of fracture away from the middle of the gauge length.



$w \leq 4t$

$w < D/8$

Figure 5 — Tensile test piece

10.3 Bend test and flattening test

10.3.1 Bend test

10.3.1.1 The bend test shall be carried out on two test pieces obtained by cutting either one or two rings with a width of 25 mm or 4 t, whichever is greater, into equal parts (see Figure 4). Each test piece shall be of sufficient length to permit the bend test to be carried out correctly. Only the edges of each strip may be machined.

10.3.1.2 The test piece shall not crack when bent inwards around the former until the inside surfaces are not further apart than the diameter of the former (see Figure 6).

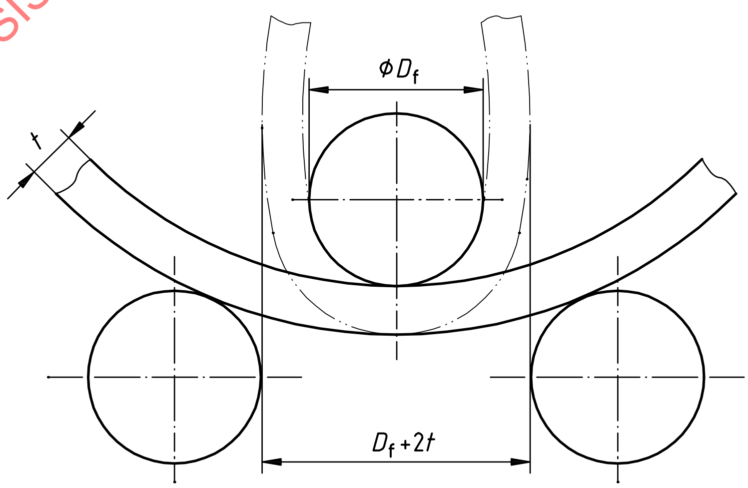


Figure 6 — Illustration of the bend test

10.3.1.3 The diameter of the former, D_f, shall be established from Table 1.

For the actual tensile strength, R_{ma}, given in Table 1, $D_f \leq n \times$ the test piece thickness, t.

10.3.2 Flattening test

10.3.2.1 The flattening test shall be performed on one cylinder selected after the heat treatment.

10.3.2.2 The test cylinder shall be flattened between the wedge-shaped knife edges with a 60° included angle, the edges being rounded to a nominal radius of 13 mm. The length of the wedges shall be not less than the width of the flattened cylinder. The longitudinal axis of the cylinder shall be at an angle of approximately 90° to the knife edges.

10.3.2.3 The test cylinder shall be flattened until the distance between the knife edges is in accordance with Table 1. Distance between knife edges or platens $\leq u \times t_m$, where t_m is the average cylinder wall thickness at the position of testing. The flattened cylinder shall remain visually uncracked.

Table 1 — Bend test and flattening test requirements

Actual tensile strength, R_{ma} MPa	Bend test n	Flattening test (cylinder or ring) u[a]
$R_m \leq 440$	2	6
$440 < R_m \leq 520$	3	6
$520 < R_m \leq 600$	4	6
$600 < R_m \leq 700$	5	7
$700 < R_m \leq 800$	6	8
$800 < R_m \leq 900$	7	9
$R_m > 900$	8	9

10.3.3 Ring flattening test

The ring flattening test shall be carried out on one ring with a width of 25 mm or 4 t, whichever is greater, taken from the cylinder body. Only the edges of the ring may be machined. The ring shall be flattened between the platens until the distance between the platens is in accordance with Table 1. The flattened ring shall remain visually uncracked.

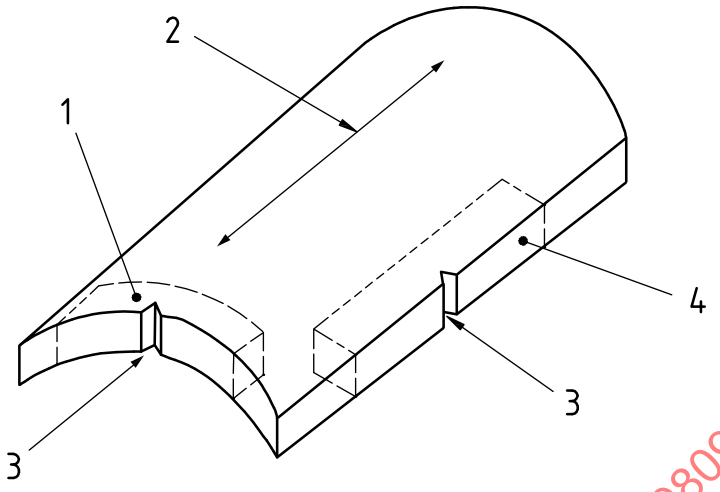
10.4 Impact test

10.4.1 For cylinders made from austenitic stainless steel, impact tests are not required. They are only required for ferritic and martensitic steels.

10.4.2 Except for the requirements set out in this subclause, the test shall be carried out in accordance with ISO 148-1.

The impact test pieces shall be taken in the direction as required in Table 2 from the wall of the cylinder. The notch shall be perpendicular to the face of the cylinder wall (see Figure 7). For longitudinal tests, the test piece shall be machined all over (on six faces). If the wall thickness does not permit a final test piece width of 10 mm, the width shall be as near as practicable to the nominal thickness of the cylinder wall. The test pieces taken in the transverse direction shall be machined on four faces only, the outer face of the cylinder wall unmachined and the inner face optionally machined as shown in Figure 8.

10.4.3 Minimum acceptance values shall be as given in Table 2.



Key

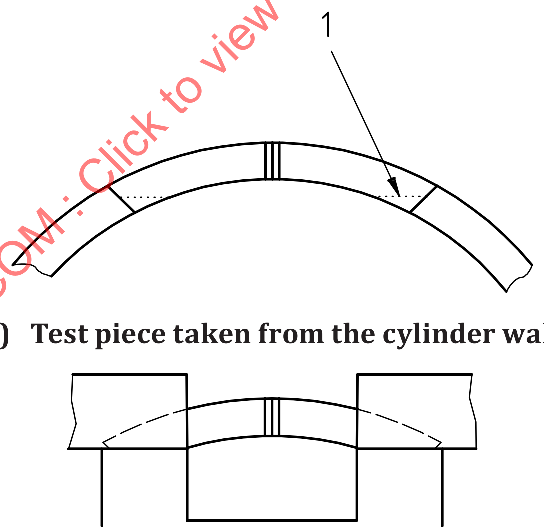
1 transverse test piece

2 cylinder longitudinal axis

3 Charpy V-notch perpendicular to the wall

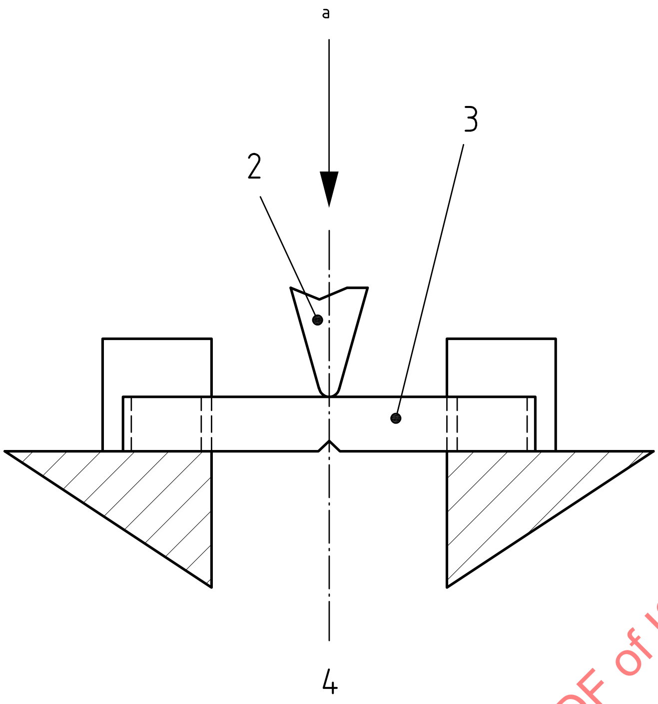
4 longitudinal test piece

Figure 7 — Description of the transverse and longitudinal impact test pieces



a) Test piece taken from the cylinder wall

b) Front view of the test piece in the impact tester



c) Top view of the test piece in the impact tester

Key

1 machining optional
2 striking anvil
3 test piece
4 centre of strike
a Direction of strike.

Figure 8 — Description of the transverse impact testing

Table 2 — Impact test acceptance values

Cylinder diameter *D*, mm	> 140			≤ 140
Direction of testing	transverse			longitudinal
Width of test piece, mm	3 to 5	> 5 to 7,5	> 7,5 to 10	3 to 10
Test temperature[a], °C	−50			−50
Impact value[b], J/cm^2				
— Mean of three test pieces	30	35	40	60
— Individual test piece	24	28	32	48

a For applications at lower temperatures, the test shall be carried out at the lowest temperature specified.

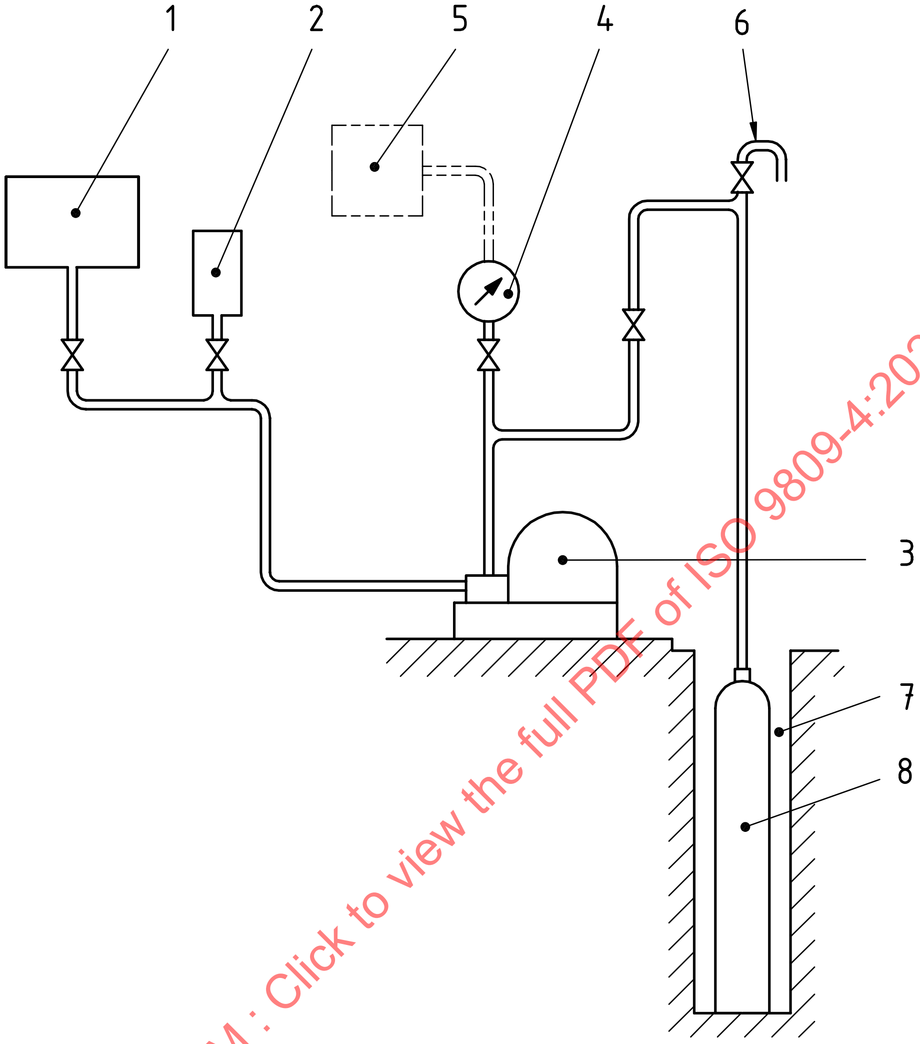
b The impact value (J/cm^2) is calculated by dividing the impact energy (J) by the actual cross-sectional area below the notch (cm^2) of the Charpy test specimen.

10.5 Hydraulic burst test

10.5.1 Test installation

The test equipment shall be capable of operating in accordance with the test conditions specified in 10.5.2 and of producing accurately the information specified in 10.5.3.

A typical hydraulic burst test installation is illustrated in Figure 9.



Key

1 test fluid reservoir
2 tank for measuring the test fluid (the test fluid reservoir can also be used as the measuring tank.)
3 pump
4 pressure gauge
5 pressure/time curve recorder
6 vent or air-release valve
7 test well
8 cylinder

Figure 9 — Typical hydraulic burst test installation

10.5.2 Test conditions

As the cylinder and test equipment are being filled with water, care shall be taken to ensure that no air is trapped in the circuit by operating the hydraulic pump until water is discharged from the vent or air-release valve. During the test, pressurization shall be carried out in two successive stages.

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

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

10.5.3 Interpretation of test results

10.5.3.1 Interpretation of the burst test results shall involve:

a) examination of the pressure/time curve or pressure/volume-of-water-used curve, to determine the pressure at which the plastic deformation of the cylinder commences, together with the burst pressure;

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

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

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

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

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

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

10.5.3.3 The cylinder shall remain in one piece and shall not fragment.

10.5.3.4 The main fracture shall be in the cylindrical portion and shall not be brittle, i.e. the fracture edges shall be inclined with respect to the wall. The tear shall not reveal a significant defect in the metal and in no case shall reach the neck. For concave bases, the tear shall not run further than the cylindrical body at the base end and, for convex bases, the tear shall not reach the centre of the base.

10.5.3.5 Acceptance criteria

The fracture shall be acceptable only if it conforms to one of the following descriptions.

a) For quenched and tempered cylinders:

— longitudinal, without branching (see Figure 10);

— longitudinal, with a side branching at each end which in no case extends beyond the longitudinal plane normal to the fracture plane ($c_1 \leq D/4$; see Figure 11).

b) For cryoformed or solution-annealed cylinders:

— longitudinal, without branching (see Figure 10);

— longitudinal, with a side branching at each end which in no case exceeds half the cylinder circumference ($c_2 \leq D/2$; see Figure 12).

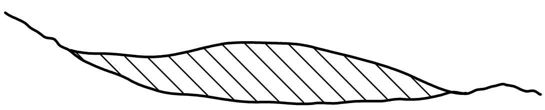


Figure 10 — Acceptable burst profiles: longitudinal without branching

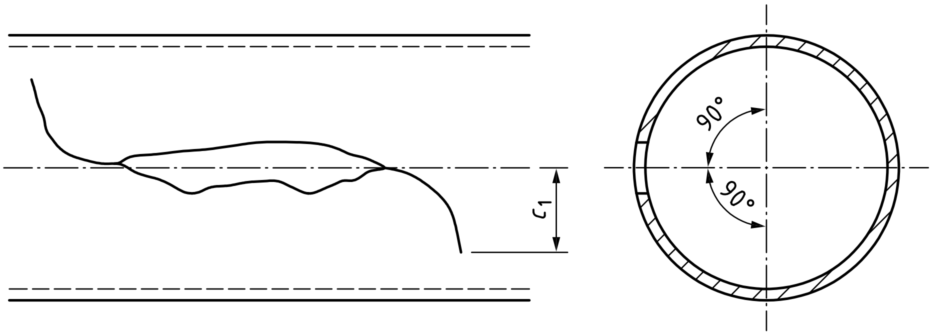


Figure 11 — Acceptable burst profiles: longitudinal with side branching, $c_1 < (\pi D/4)$

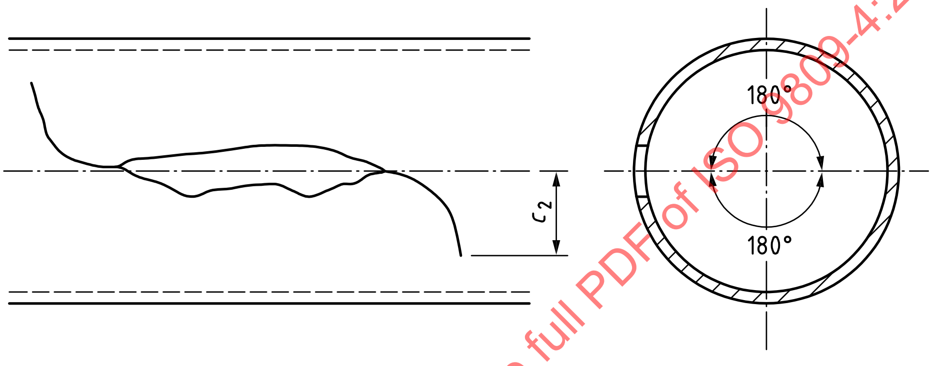


Figure 12 — Acceptable burst profiles for cryoformed or solution annealed cylinders only: longitudinal with side branching, $c_2 < (\pi D/2)$

10.6 Intergranular corrosion test

This test is required on austenitic and duplex stainless steel grades only.

The test shall be carried out in accordance with ISO 3651-2.

The test requires that the specimens be taken from a part of the cylinder that provides specimen geometry suitable for bend testing, see Figure 4.

11 Tests/examinations on every cylinder

11.1 General

During production, the examinations specified in 8.2 and 8.4 shall be carried out on all cylinders.

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

— A hydraulic proof pressure test in accordance with 11.2.1 or a hydraulic volumetric expansion test in accordance with 11.2.2. The test method requirements are given in 11.2. Additional guidance for these test methods and equipment control (calibration and maintenance) can be found in ISO 18119. The purchaser and the manufacturer shall agree on which of these alternatives shall be carried out.

— A hardness test in accordance with 11.3.

— A leak test in accordance with 11.4, if the cylinder is manufactured from tube with a closed end (e.g. by spinning or threaded plug).

— A water capacity check in accordance with 11.5.

11.2 Hydraulic test

11.2.1 Proof pressure test

The water pressure in the cylinder shall be increased at a controlled rate until the test pressure, p_h, is reached within a measuring tolerance of 0/+3 % or +10 bar, whichever is lower.

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. During the period that the cylinder is under test pressure, it shall be visible (including the base) and remain dry. After the test, the cylinder shall show no visible permanent deformation and no trace of moisture implying leakage.

11.2.2 Volumetric expansion test

The water pressure in the cylinder shall be increased at a controlled rate until the test pressure, p_h, is reached within a measuring tolerance of 0/+3 % or +10 bar, whichever is lower.

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

The cylinder shall be rejected if it shows a permanent expansion (i.e. a volumetric expansion after the pressure has been released) in excess of 10 % of the total volumetric expansion measured at the test pressure, p_h.

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

11.3 Hardness test

A hardness test in accordance with ISO 6506-1 (Brinell), ISO 6508-1 (Rockwell) or other equivalent methods shall be carried out by the manufacturer. The hardness values thus determined shall be within the limits specified by the cylinder manufacturer for the material, dependent upon the heat treatment used for the production of the cylinder and the intended gas service (e.g. embrittling gases).

NOTE 1 Methods for measuring the surface indentations other than those given in ISO 6506-1 or ISO 6508-1 can be used subject to agreement between the parties concerned provided that an equal level of accuracy can be demonstrated.

NOTE 2 The hardness value at any single location can be the result of the average of a maximum of three test results.

11.4 Leak test

Only for cylinders with base ends formed from tube, 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.

The following are examples of typical testing procedures:

— A pneumatic leakage test where the bottom end can be clean and free from all moisture on the test pressure side. The inside area of the cylinder bottom surrounding the closure can be subjected to a pressure equal to at least 2/3 times the test pressure of the cylinder for a minimum of 1 min. This area shall not be less than 20 mm in diameter around the closure and at least 6 % of the total bottom area. The opposite side shall be covered with water or another suitable medium and closely examined for indication of leakage.

— Alternative tests on finished cylinders (e.g. helium leak test or pneumatic leakage test).

For both the above leak testing procedures, cylinders that leak shall be rejected.

11.5 Capacity check

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

12 Certification

Each batch of cylinders shall be covered by a certificate signed by the inspector to the effect that the cylinders meet the requirements of this document in all respects. A certificate can cover several batches of cylinders. Annex D provides a typical example of a suitability worded acceptance certificate. Other formats with at least the same content are also acceptable.

Copies of the certificate shall be issued to the manufacturer. The original certificate shall be retained by the inspector and the copies by the manufacturer.

NOTE Regarding certificates, national regulations can contain additional or overriding requirements.

13 Marking

Each cylinder shall be permanently marked on the shoulder, or on a reinforced part of the cylinder or on a permanently fixed collar or neck ring, in accordance with ISO 13769.

In addition, the grade of stainless steel may be stamp marked (e.g. “316L”).

NOTE Regarding marking, national regulations can contain additional or overriding requirements.

Annex A
(normative)

Description and evaluation of manufacturing imperfections and conditions for rejection of seamless steel gas cylinders at the time of final inspection by the manufacturer

A.1 Overview

Several types of imperfections can occur during the manufacture of seamless gas cylinders.

Such imperfections can be due to material defects, the manufacturing process, handling and other circumstances during the manufacturing process.

The aim of this annex is to identify the manufacturing imperfections most commonly found on finished cylinders and to provide requirements for the visual inspection at the stage of product acceptance.

NOTE 1 This annex does not address customer specifications, e.g. cylinder aesthetics, special surface preparations.

NOTE 2 Cylinder sampling method(s) and the quantity sampled for inspection, after cylinders with imperfections have been found, are not covered by this annex and are prescribed in 10.1.2.

NOTE 3 Manufacturing imperfections can be identified and evaluated at any stage of the manufacturing process.

NOTE 4 On small diameter cylinders, these general limits could have to be adjusted. Consideration of appearance also plays a part in the evaluation of dents, especially in the case of small cylinders.

NOTE 5 Consideration of appearance and localization (in thicker parts with lower stresses) can be taken into account.

A.2 General

A.2.1 The visual inspection shall be conducted in good lighting on a product that is clean, dry and suitable enough for proper inspection of all surfaces. The visual inspection shall be conducted by eye, and internal inspections can be augmented by a scope, dental mirror or other suitable device. Where magnification is used, the final assessment of the imperfection shall be evaluated as if no magnification had been used.

In thicker parts of the cylinder, the acceptable absolute value of the size of the imperfection can be proportionately increased to the thickness, provided that it does not adversely affect the safe performance or integrity of the cylinder.

Where needed, the severity of a detected imperfection can be further evaluated by the use of other devices or methods.

If unclean, the cylinder surfaces should be re-cleaned before submitting the cylinder for inspection.

A.2.2 If appropriate, small imperfections, as permitted by Table A.1, can be removed by local dressing, grinding, machining or other suitable methods. Great care shall be taken to avoid introducing new defects or imperfections.

After such a repair, the cylinders shall be re-examined, and if the wall thickness is reduced, it shall be rechecked and be at least at minimum guaranteed wall thickness.

A.3 Manufacturing imperfections and the procedure for their evaluation

The most commonly found safety- and performance-related manufacturing imperfections and their descriptions are listed in Table A.1.

In addition, the manufacturing imperfections and their descriptions for features which are not safety- or performance-related (cosmetic) are listed in Table A.2.

Limits for the repair or rejection of cylinders manufactured to this document are included in Table A.1.

The acceptance or rejection conditions for gas cylinders are categorized into three levels, in accordance with A.4.

The process that shall be followed at the final visual inspection is given in Figure A.1.

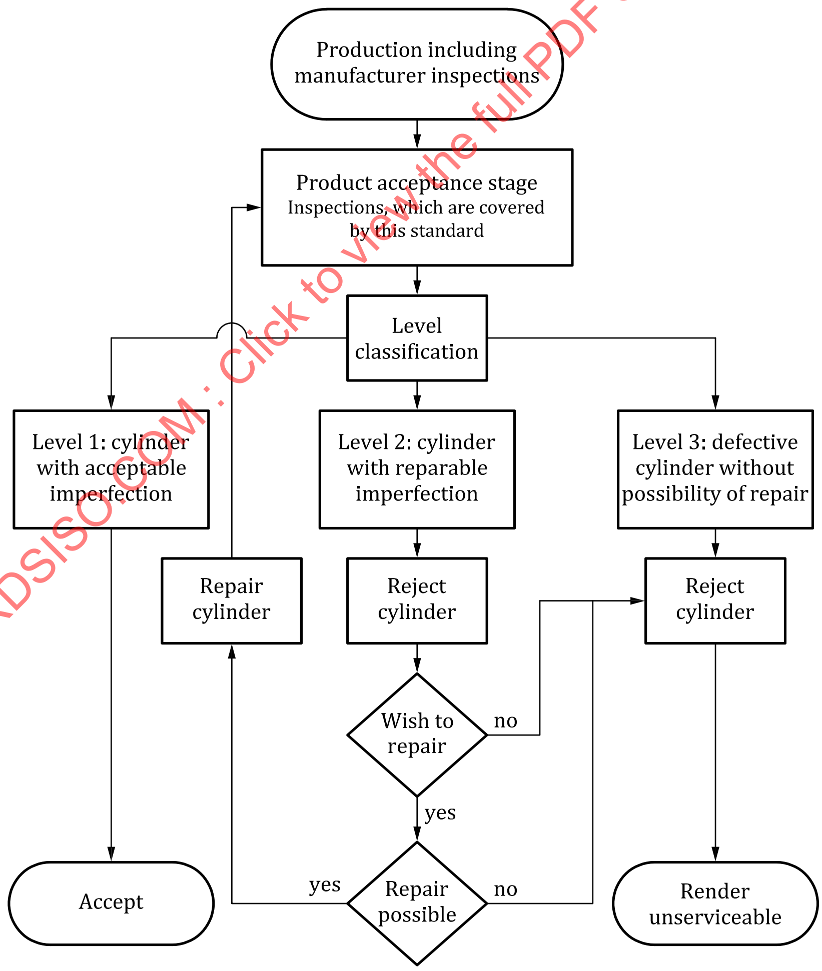


Figure A.1 — Flow-diagram for the final visual inspection of gas cylinders at the time of product acceptance

A.4 Acceptance and rejection conditions

The following categorize the levels of imperfections and provide instructions depending on the severity of the imperfection and regarding the disposition of the cylinders.

Level 1 imperfection

Conforming condition of a cylinder that has no adverse effects on the safe performance or integrity of the cylinder. Cylinders with Level 1 imperfections are acceptable and do not require repair.

Level 2 imperfection

Non-conforming condition of a cylinder with features more severe than Level 1 imperfections. Cylinders with Level 2 imperfections shall be rejected. If it is decided that a rejected cylinder with Level 2 imperfections is to be repaired, it shall be repaired in accordance with A.2.2 and be re-inspected. Otherwise, the cylinders are to be treated as cylinders with Level 3 imperfections.

Level 3 imperfection

Non-conforming condition of a cylinder with features more severe than Level 2 imperfections. Cylinders with Level 3 imperfections shall be rejected. Rejected cylinders with Level 3 imperfections shall not be repaired and shall be rendered unserviceable.

The cylinders presented to the inspector for inspection at the time of product acceptance should have been found acceptable by the manufacturer and should be free of imperfections to Levels 2 and 3.

Table A.1 — Safety- and performance-related manufacturing imperfections and their evaluation for seamless steel cylinders

Pos	Type of imperfection	Description	Decision at the time of inspections and follow-up actions			Additional requirements
			Level 1 imperfection Acceptable	Level 2 imperfection Reject and repair if possible (for repairs, see A.2.2)	Level 3 imperfection Reject and render unserviceable	
1	Bulge	A visible swelling of the wall (see Figure A.2).			All cylinders with such imperfection.	The cause of such failure shall be identified.
2	Dent (flat)	A visible depression in the wall that has neither penetrated nor removed metal and is greater in depth than 0,5 % of the external cylinder diameter (see Figure A.3). (See also excessive grinding or machining.)	When the depth of the dent is less than 1 % of the external-cylinder diameter and when the diameter[a] of the dent is greater than 30 times its depth.		When the depth of the dent exceeds 1 % of the external-cylinder diameter or when the diameter[b] of the dent is less than 30 × its depth.	In all cases, the wall thickness shall be verified at the imperfection area and shall not be less than the guaranteed minimum wall thickness.
3	Dent containing cut or gouge	A depression in the wall (see item 2 S) which contains a cut or gouge (See item 4 S). (See Figure A.4.)			All cylinders with such imperfections.	
4	Cut, gouge, groove, metallic or scale impression	An impression in the wall where metal has been removed, displaced or redistributed with a depth of greater than 3 % of the guaranteed minimum wall thickness (see Figure A.5).	When the depth does not exceed 5 % of the guaranteed minimum wall thickness and there are no sharp notches longer than 10 times the guaranteed minimum wall thickness.	External surface imperfection in excess of Level 1. They can be dressed provided that the remaining wall thickness below defect is greater than the guaranteed minimum wall thickness.	Internal surface imperfection in excess of Level 1. External surface imperfection in excess of Level 1 which has not been repaired or cannot be repaired.	
5	Excessive grinding or machining	A local reduction of wall thickness by grinding or machining or other mechanical metal removal process.			When the wall thickness is reduced to below the guaranteed minimum wall thickness.	When it results in the formation of a dent or grinding mark, treat it as "dent" (item 2) or "cut" (item 3).

[a] If the dent is not circular, the smallest dimension shall be taken as diameter.

[b] If the dent is not circular, the largest dimension shall be taken as diameter.

Table A.1 *(continued)*

Pos	Type of imperfection	Description	Decision at the time of inspections and follow-up actions			Additional requirements
			Level 1 imperfection Acceptable	Level 2 imperfection Reject and repair if possible (for repairs, see A.2.2)	Level 3 imperfection Reject and render unserviceable	
6	Lamination	A layering of the material with a surface-breaking imperfection sometimes, appearing as a discontinuity, crack, lap or bulge at the surface (see Figure A.6).		External imperfection: all cylinders with such imperfection.	Internal imperfection: all cylinders with such imperfection.	Laminations can exist within the entire surface of the cylinder and can appear as bulge or blister on the surface.
7	Crack	A split or separation in the metal, typically appearing as a line on the surface.		When removable within thickness tolerance, i.e. the remaining wall thickness below defect is greater than the guaranteed minimum wall thickness.	When not removable within the thickness tolerance.	
8	Neck cracks and tap marks	A split or separation in the material, typically appearing as lines usually running down/up vertically the thread and across the thread. (see Figure A.7). They shall not be confused with tap marks/thread machining marks typically appearing as straight line (see Figure A.8).	Only cylinders with tap marks.		All cylinders with neck cracks.	Unlike tap marks, cracks can appear on the top face of the cylinder neck.

[a] If the dent is not circular, the smallest dimension shall be taken as diameter.

[b] If the dent is not circular, the largest dimension shall be taken as diameter.

Table A.1 *(continued)*

Pos	Type of imperfection	Description	Decision at the time of inspections and follow-up actions			Additional requirements
			Level 1 imperfection Acceptable	Level 2 imperfection Reject and repair if possible (for repairs, see A.2.2)	Level 3 imperfection Reject and render unserviceable	
9	Internal shoulder folds	Metal flows in the shoulder area creating a visual groove. The groove of the fold will always be in longitudinal direction which can propagate into the threaded part of the neck (see Figure A.9, key 1). Folds can be the initiation point for cracks, which can propagate into the cylindrical machined or threaded area of the shoulder (see Figure A.7, key 3).	Folds which are clearly visible as open depressions where no oxides have been trapped into the metal shall be accepted, provided that the peaks are smooth and the bottom (valley) of the depression is rounded. Minor sharp folds are acceptable, provided they do not adversely affect the safety of the cylinder (see Figure A.10).	Folds in excess of Level 1 which can be removed by a machining operation until the lines of oxide are no longer visible and provided that the remaining thickness meets the design criteria (see Figure A.9, key 2).	Repaired Level 2 folds where the lines are still visible.	
10	a) Features on internal-base surface on cylinders made from tube	Splits (resembling cracks), porosity, and remaining oxides on the central surface of the cylinder base (e.g. in star form, see Figure A.11).		When removable within the thickness tolerance.	When not removable within the thickness tolerance.	
	b) Other base features	Splits, cracks, porosity, toolmarks and scale impressions of the cylinder base.	Tool marks and scale impressions provided they have been shown not to adversely affect the safety or performance of the cylinder.	Features in excess of Level 1 and when removable within the thickness tolerance.	When not removable within the thickness tolerance.	
11	"Orange peel" surface	A mottled, rough and slightly wavy appearance on the internal surface due to discontinuous metal flow (see Figure A.12).	If no cracks are visible in the orange peel surface.		If cracks are visible in the orange peel surface.	

[a] If the dent is not circular, the smallest dimension shall be taken as diameter.

[b] If the dent is not circular, the largest dimension shall be taken as diameter.

Table A.1 *(continued)*

Pos	Type of imperfection	Description	Decision at the time of inspections and follow-up actions: Level 1 imperfection Acceptable	Level 2 imperfection Reject and repair if possible (for repairs, see A.2.2)	Level 3 imperfection Reject and render unserviceable	Additional requirements
12	Damaged internal neck threads or missing threads	Damaged neck threads, e.g. with dents, cuts, burrs and chipped, stripped or missing threads. For chipped threads, see Figure A.13.	All tap marks. Superficial damage which has been shown not to adversely affect the safety or performance of the cylinder.	Features in excess of Level 1 and when the design permits it, threads can be retapped/reworked and rechecked by the appropriate thread gauge and carefully visually re-examined. The required number of effective threads shall be present.	Features in excess of Level 1 and not repaired or inappropriate number of effective threads.	In case of doubt, the visual inspection can be augmented (see A.2.1).
13	Pitting	Small holes in the metal due to chemical or water attack (see Figure A.14).		All pits regardless of size can be removed, provided that the requirements of A.2.2 are met.	All cylinders with such imperfections which are not repaired or the remaining wall thickness is less than the guaranteed minimum wall thickness.	
14	Nonconformity with the design drawing and/or technical specification	A feature at the time of visual inspection that does not conform with the design drawing and/or technical specification.		All such cylinders can be repaired or be accepted, provided that the cylinder complies with the type approval and is acceptable to all parties concerned.	All cylinders not meeting Level 2. Such cylinders can be rerouted to another design drawing and/ or technical specification, provided that they meet the type approval.	
15	Neck ring not secure	A neck ring is loose by manual handling.		All cylinders presenting such an imperfection can be repaired.	All cylinders presenting such an imperfection and are not repaired.	
16	Internal contamination	Visual foreign matters such as loose particles, liquids, paint, lubricants and turnings.	Discolouration (thin oxide layer) which is not detrimental to the intended gas service.	All cylinders with visually internal contamination. Such cylinders can be cleaned.	All cylinders with such imperfections which are not repaired.	The cause of the contamination shall be determined.

[a] If the dent is not circular, the smallest dimension shall be taken as diameter.

[b] If the dent is not circular, the largest dimension shall be taken as diameter.

Table A.1 *(continued)*

Pos	Type of imperfection	Description	Decision at the time of inspections and follow-up actions			Additional requirements
			Level 1 imperfection Acceptable	Level 2 imperfection Reject and repair if possible (for repairs, see A.2.2)	Level 3 imperfection Reject and render unserviceable	
17	Internal ridge or rib	A raised surface with sharp corners at its base (see Figure A.15).		When corners can be rounded by internal blasting.	All cylinders with such imperfections which are not repaired.	

[a] If the dent is not circular, the smallest dimension shall be taken as diameter.

[b] If the dent is not circular, the largest dimension shall be taken as diameter.

Table A.2 — Cosmetic manufacturing imperfections for seamless steel cylinders

Pos	Type of imperfection	Description	Decision at the time of inspections and follow-up actions			Note
			Level 1 imperfection Acceptable	Level 2 imperfection Reject and repair if possible (for repairs see A.2.2)	Level 3 imperfection Reject and render unserviceable	
18	External ridge or rib	A raised surface with rounded or sharp corners at its base (see Figure A.15).	NOTE As these imperfections are not safety- or performance related, they are deemed acceptable.			This is not a harmful imperfection. However, ribs can be confused with weldment during the use of the cylinder.

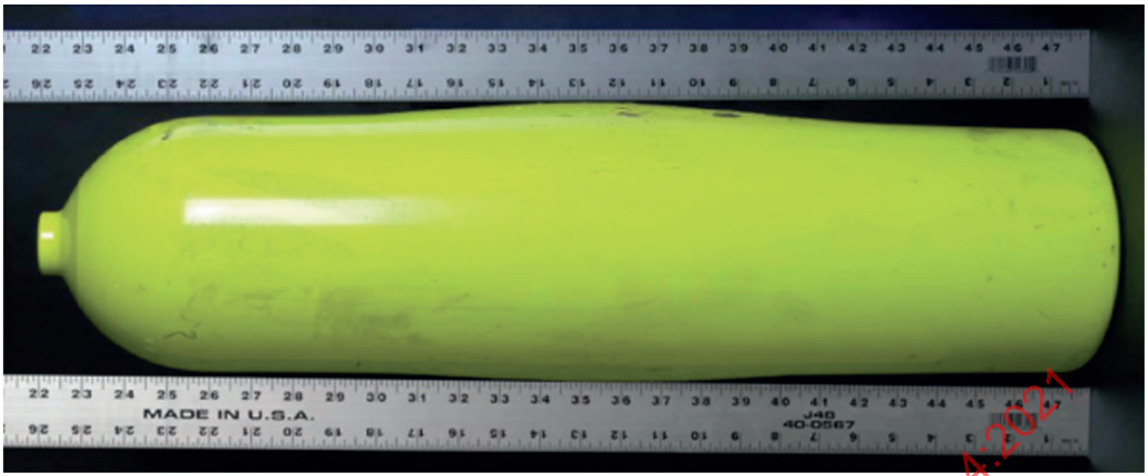


Figure A.2 — Bulge

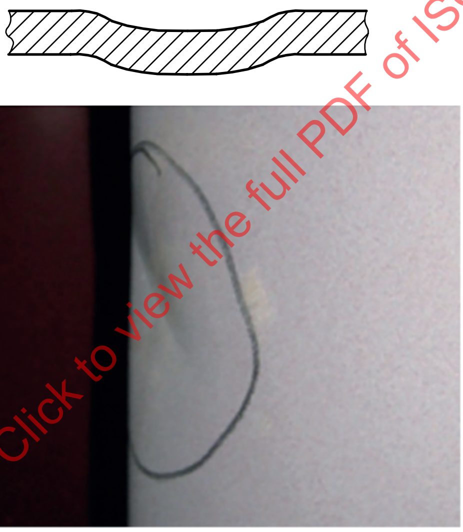


Figure A.3 — Dent

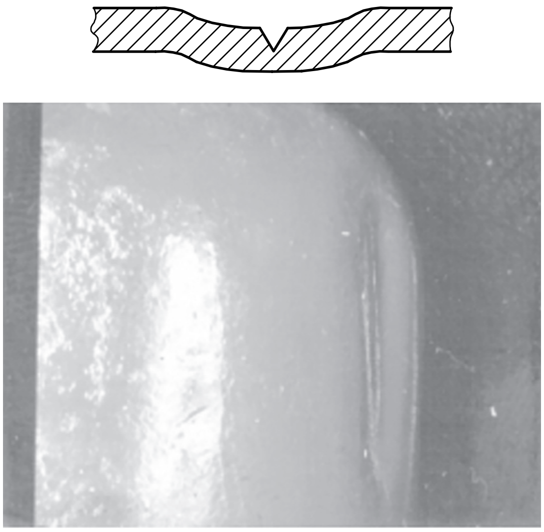
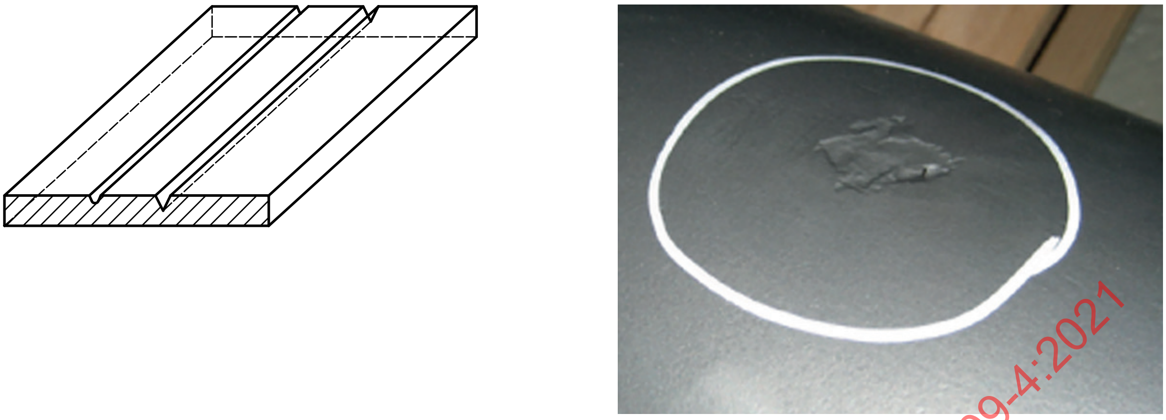


Figure A.4 — Dent containing cut or gouge



a) Groove, cut

b) Metallic or scale impression

Figure A.5 — Impression in a wall

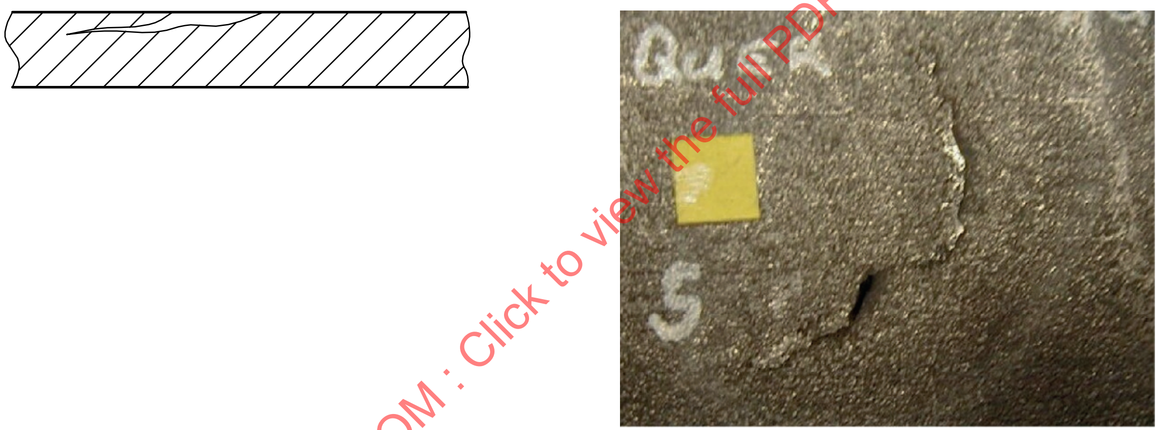
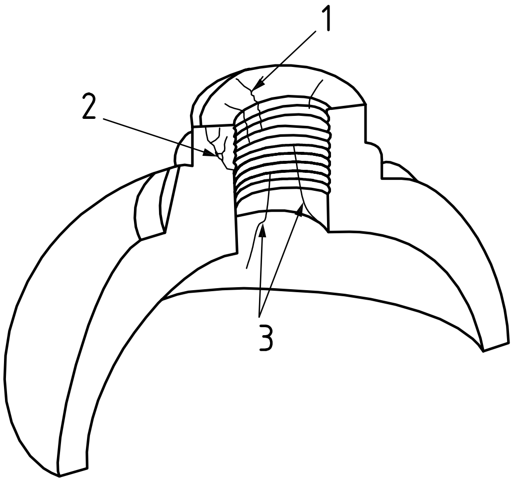


Figure A.6 — Lamination



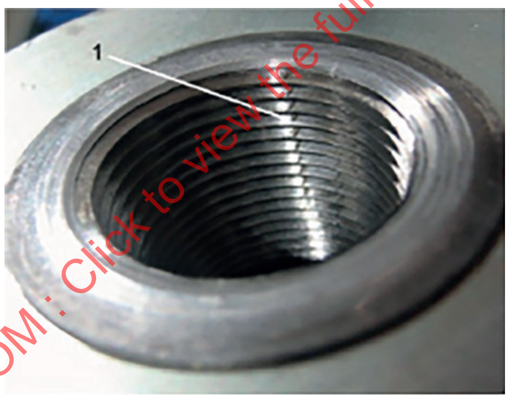
Key

1 cylinder neck cracks

2 cross-section of cylinder neck

3 neck crack/shoulder crack

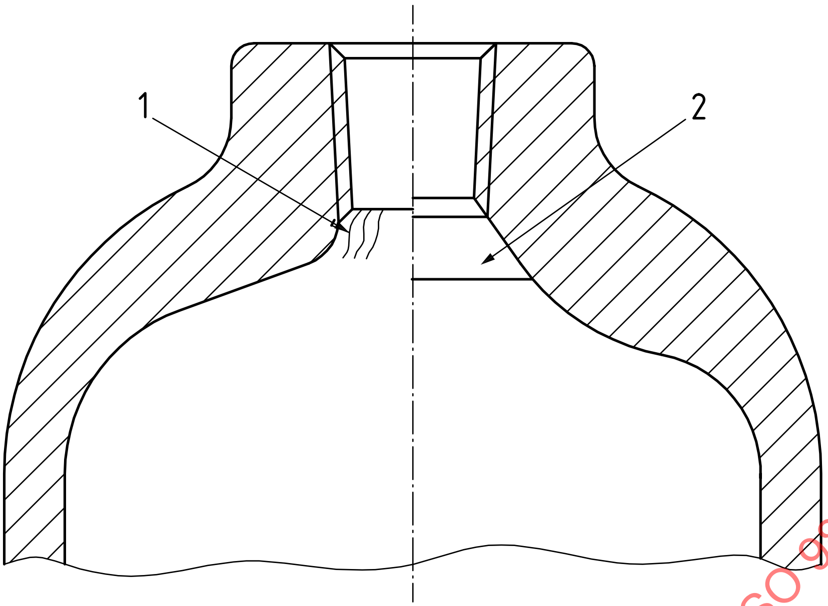
Figure A.7 — Neck cracks



Key

1 tap mark

Figure A.8 — Tap marks

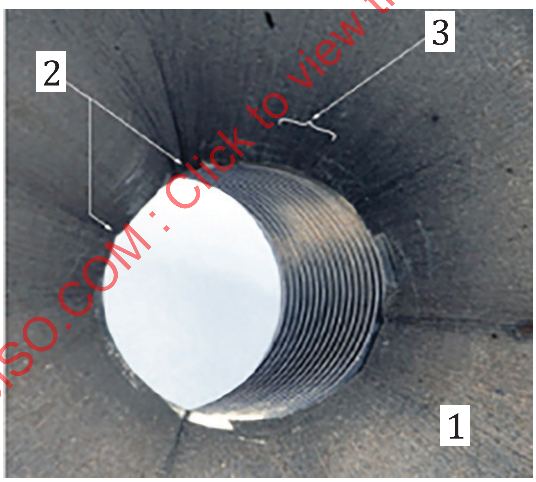


Key

1 folds or cracks

2 after machining

Figure A.9 — Cylinder shoulder folds or cracks before and after machining



Key

1 area of fine/small folds

2 minor sharp folds

3 rounded depressions (valley)

Figure A.10 — Examples of shoulder folds

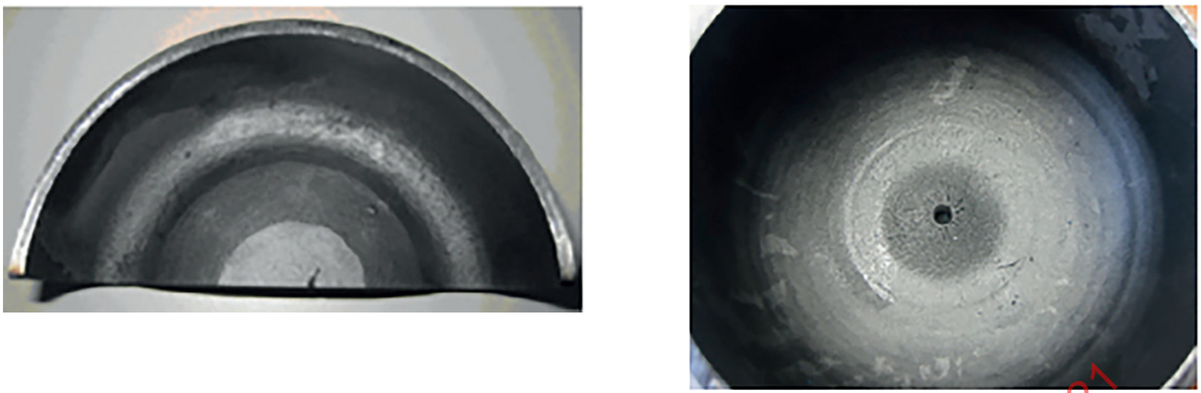


Figure A.11 — Features on cylinder base made from tube

Figure A.12 — Orange peel

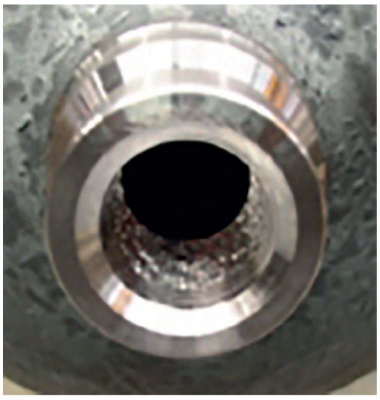


Figure A.13 — Chipped threads

Figure A.14 — Pitting

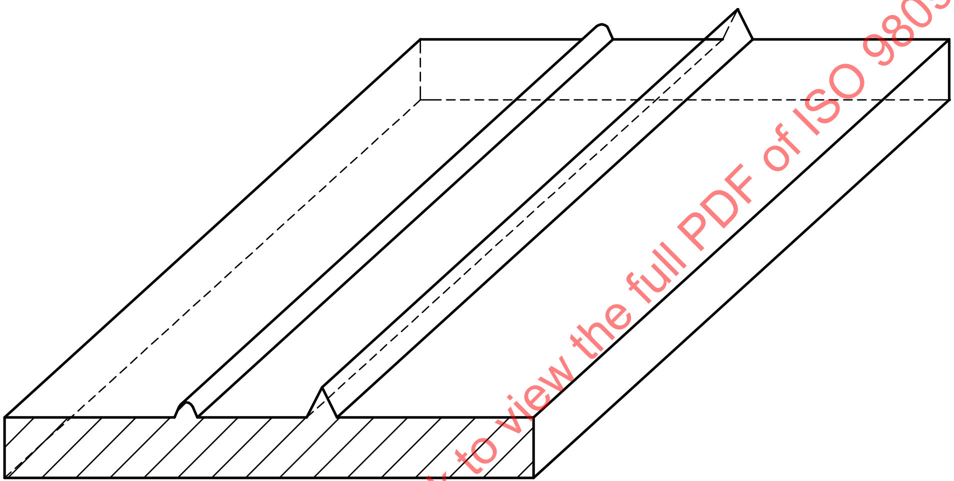


Figure A.15 — Rib

Annex B
(normative)

Ultrasonic examination

B.1 General

This annex is based on techniques used by cylinder manufacturers. Other techniques of ultrasonic examination can be used, provided that these have been demonstrated to be suitable for the manufacturing method.

B.2 General requirements

The ultrasonic examination equipment shall be capable of at least detecting the reference standard notches as described in B.3.2. It shall be serviced regularly in accordance with the manufacturer's operating instructions to ensure that its accuracy is maintained. The inspection records and approval certificates for the equipment shall be maintained.

The operation of the ultrasonic examination equipment shall be by qualified and experienced personnel certified at least to Level 1 and supervised by personnel certified at least to Level 2 in accordance with ISO 9712. Other standards which meet or exceed these minimum requirements can be used subject to the approval of the inspector. The inner and outer surfaces of any cylinder which is to be examined ultrasonically shall be in a condition suitable for an accurate and reproducible examination.

For flaw detection, the pulse echo system shall be used. For thickness measurement, either the resonance method or the pulse echo system shall be used. Either the contact or immersion techniques of examination shall be used.

A coupling method which ensures adequate transmission of ultrasonic energy between the test probe and the cylinder shall be used.

B.3 Flaw detection of the cylindrical parts

B.3.1 Procedure

The cylinders to be examined and the search unit shall go through a rotating motion and translation relative to one another such that a helical scan is performed on the cylinder. The velocity of the rotation and translation shall be constant within ±10 %. The pitch of the helix shall be less than the width covered by the probe (at least a 10 % overlap shall be guaranteed) and be related to the effective beam width such as to ensure 100 % coverage at the velocity of the rotational and translation used during the calibration procedure.

An alternative scanning method may be used for detection of transverse imperfections, in which the scanning or relative movement of the probes and the work piece is longitudinal, the sweeping motion being such as to ensure a 100 % surface coverage with approximately 10 % overlapping of the sweeps.

The cylinder wall shall be examined for longitudinal imperfections with the ultrasonic energy transmitted in both circumferential directions and, for transverse imperfections, in both longitudinal directions.

For concave-based cylinders where hydrogen embrittlement or stress corrosion can occur (see ISO 11114-1), the transition region between the cylindrical part and the cylinder base shall also be examined for transverse imperfections in the direction of the base. For the area to be considered, see

