
**Gas cylinders — Refillable seamless steel
gas cylinders — Design, construction and
testing —**

Part 1:

Quenched and tempered steel cylinders with
tensile strength less than 1 100 MPa

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

*Partie 1: Bouteilles en acier trempé et revenu ayant une résistance à la
traction 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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 9809-1 was prepared by Technical Committee ISO/TC58, *Gas cylinders*, Subcommittee SC 3, *Cylinder design*.

ISO 9809 consists of the following parts, under the general title *Gas cylinders — Refillable seamless steel gas cylinders — Design, construction and testing*:

- *Part 1: Quenched and tempered steel cylinders with tensile strength less than 1 100 MPa*
- *Part 2: Quenched and tempered steel cylinders with tensile strength greater than or equal to 1 100 MPa*
- *Part 3: Normalized steel cylinders*

Annex B forms an integral part of this part of ISO 9809. Annexes A, C and D are for information only.

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Introduction

The purpose of ISO 9809 is to provide a specification for the design, manufacture, inspection and testing of a seamless steel cylinder for worldwide usage. The objective is to balance design and economic efficiency against international acceptance and universal utility.

ISO 9809 aims to eliminate the concern about climate, duplicate inspections and restrictions currently existing because of lack of definitive International Standards and should not be construed as reflecting on the suitability of the practice of any nation or region.

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Gas cylinders — Refillable seamless steel gas cylinders — Design, construction and testing —

Part 1:

Quenched and tempered steel cylinders with tensile strength less than 1 100 MPa

1 Scope

This part of ISO 9809 specifies minimum requirements for the material, design, construction and workmanship, manufacturing processes and tests at manufacture of refillable quenched and tempered seamless steel gas cylinders of water capacities from 0,5 l up to and including 150 l for compressed, liquefied and dissolved gases exposed to extreme world-wide ambient temperatures (normally between $-50\text{ }^{\circ}\text{C}$ and $+65\text{ }^{\circ}\text{C}$). This part of ISO 9809 is applicable to cylinders with a maximum tensile strength R_m of less than 1 100 MPa.

NOTE 1 If so desired, cylinders of water capacity less than 0,5 l may be manufactured and certified to this part of ISO 9809.

NOTE 2 For quenched and tempered cylinders with maximum tensile strength greater than or equal to 1 100 MPa refer to ISO 9809-2. For normalized steel cylinders refer to ISO 9809-3.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of ISO 9809. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of ISO 9809 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 148:1983¹⁾, *Steel — Charpy impact test (V-notch)*.

ISO 2604-2:1975, *Steel products for pressure purposes — Quality requirements — Part 2: Wrought seamless tubes*.

ISO 6506:1981²⁾, *Metallic materials — Hardness test — Brinell test*.

ISO 6508:1986³⁾, *Metallic materials — Hardness test — Rockwell test (scales A-B-C-D-E-F-G-H-K)*.

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

ISO 7438:1985, *Metallic materials — Bend test*.

ISO 9712:1999, *Non-destructive testing — Qualification and certification of personnel*.

¹⁾ To be withdrawn and replaced by ISO 148-1, ISO 148-2 and ISO 148-3.

²⁾ To be withdrawn and replaced by ISO 6506-1, ISO 6506-2 and ISO 6506-3.

³⁾ To be withdrawn and replaced by ISO 6508-1, ISO 6508-2 and ISO 6508-3.

ISO 11114-1:1997, *Transportable gas cylinders — Compatibility of cylinder and valve materials with gas contents — Part 1: Metallic materials.*

ISO 13769:—⁴⁾, *Gas cylinders — Stamp marking.*

3 Terms and definitions

For the purposes of this part of ISO 9809 the following definitions apply.

3.1

yield stress

value corresponding to the upper yield stress, R_{eH} or, for steels that do not exhibit a defined yield, the 0,2 % proof stress (non-proportional elongation), $R_{p0,2}$ (see ISO 6892)

3.2

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 in a suitable medium

3.3

tempering

softening heat treatment which follows quenching, in which the cylinder is heated to a uniform temperature below the lower critical point, A_{c1} , of the steel

3.4

batch

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

NOTE The lengths of the cylinders in a batch may vary by $\pm 12\%$.

3.5

test pressure (p_H)

pressure required applied during a pressure test.

NOTE It is used for cylinder wall thickness calculation.

3.6

design stress factor, (F)

ratio of the equivalent wall stress at the test pressure (p_H) to the guaranteed minimum yield stress (R_e).

4 Symbols

- | | |
|-------|--|
| 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). |
| A | Percentage elongation. |

⁴⁾ To be published.

<i>b</i>	Guaranteed minimum thickness, in millimetres, at the centre of a convex base (see Figure 1).
<i>c</i>	Maximum permissible deviation of burst profile, in millimetres (see Figures 10 and 11).
<i>D</i>	Nominal outside diameter of the cylinder, in millimetres (see Figure 1).
<i>D_f</i>	Diameter, in millimetres, of former (see Figure 6).
<i>F</i>	Design stress factor (variable) (see 3.6).
<i>h</i>	Outside depth (concave base end), in millimetres (see Figure 2).
<i>H</i>	Outside height, in millimetres, of domed part (convex head or base end) (see Figure 1).
<i>L_o</i>	Original gauge length, in millimetres, of tensile test piece as defined in ISO 6892 (see Figure 5).
<i>n</i>	Ratio of the diameter of the bend test former to actual thickness of test piece (<i>t</i>).
<i>p_b</i>	Measured burst pressure, in bar ⁵⁾ , above atmospheric pressure.
<i>p_h</i>	Hydraulic test pressure, in bar, above atmospheric pressure.
<i>p_w</i>	Working pressure, in bar, above atmospheric pressure.
<i>p_y</i>	Observed pressure when cylinder starts yielding during hydraulic bursting test, in bar, above atmospheric pressure.
<i>r</i>	Inside knuckle radius, in millimetres (see Figures 1 and 2).
<i>R_e</i>	Minimum guaranteed value of yield stress (see 3.1), in MPa.
<i>R_{ea}</i>	Actual value of the yield stress, in MPa, determined by the tensile test (see 10.2.)
<i>R_g</i>	Minimum guaranteed value of tensile strength, in MPa.
<i>R_m</i>	Actual value of tensile strength, in MPa, as determined by the tensile test (see 10.2.)
<i>S_o</i>	Original cross-sectional area of tensile test piece, in square millimetres, in accordance with ISO 6892.
<i>t</i>	Actual thickness of the test specimen, in millimetres.
<i>u</i>	Ratio of distance between knife edges or platens in the flattening test to average cylinder wall thickness at the position of test.
<i>V</i>	Water capacity of cylinder, in litres.
<i>w</i>	Width, in millimetres, of the tensile test piece (see Figure 5).

5 Inspection and testing

Evaluation of conformity is required to be performed in accordance with the relevant regulations of the country(ies) where the cylinders are used.

In order to ensure that the cylinders are in compliance with this part of ISO 9809 they shall be subject to inspection and testing in accordance with clauses 9, 10 and 11 by an authorized inspection body (hereafter referred to as "the inspector") recognized in the countries of use. The inspector shall be competent for inspection of cylinders.

⁵⁾ 1 bar = 10⁵ Pa = 10⁵ N/m²

6 Materials

6.1 General requirements

6.1.1 Materials for the manufacture of gas cylinders intended for international service 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 requirements of 6.2.1, 6.2.2 and relevant conditions of 6.2.3 shall be satisfied.

6.1.2 The material used for the fabrication of gas cylinders shall be steel, other than rimming quality, with non-ageing properties, and shall be aluminium and/or silicon killed.

In cases where examination of this non-ageing property is required by the customer, the criteria by which it is to be specified shall be agreed with the customer and inserted in the order.

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

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

6.2 Controls on chemical composition

6.2.1 The chemical composition of all steels shall be defined at least by:

- the carbon, manganese and silicon contents in all cases;
- the chromium, nickel and molybdenum contents or other alloying elements intentionally added to the steel;
- the maximum sulfur and phosphorus contents in all cases.

The carbon, manganese and silicon contents and, where appropriate, the chromium, nickel and molybdenum contents shall be given, with tolerances, such that the differences between the maximum and minimum values of the cast do not exceed the values shown in Table 1.

The combined content of the following elements: Vanadium, Niobium, Titanium, Boron and Zirconium, shall not exceed 0,15 %.

The actual content of any element deliberately added shall be reported and their maximum content shall be representative of good steelmaking practice.

Table 1 — Chemical composition tolerances

Element	Maximum content %	Permissible range %
Carbon	< 0,30 ≥ 0,30	0,06 0,07
Manganese	All values	0,30
Silicon	All values	0,30
Chromium	< 1,50 ≥ 1,50	0,30 0,50
Nickel	All values	0,40
Molybdenum	All values	0,15

6.2.2 Sulfur and phosphorus in the cast analysis of material used for the manufacture of gas cylinders shall not exceed the values shown in Table 2.

Table 2 — Maximum sulfur and phosphorus limits

	$R_m < 950$ MPa	$950 \leq R_m < 1\ 100$
Sulfur	0,020 %	0,010 %
Phosphorus	0,020 %	0,020 %
Sulfur + phosphorus	0,030 %	0,025 %

6.2.3 The cylinder manufacturer shall obtain and provide 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 specimens taken during manufacture from the material in the form as supplied by the steelmaker 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 2604-2.

6.3 Typical steels

Two typical internationally recognized steel types which have provided safe performance over many years are:

- a) chromium molybdenum steel (quenched and tempered);
- b) carbon manganese steel (quenched and tempered).

The chemical compositions of these steels, subject to the controls specified in 6.2.1, are given in table 3.

Table 3 — Internationally recognized steel compositions

Element	Steel grade and conditions	
	CrMo (Q & T)	CMn (Q & T)
Carbon	0,25 to 0,38 %	0,38 max. %
Silicon	0,1 to 0,4 %	0,1 to 0,35 %
Manganese	0,4 to 1,0 %	1,35 to 1,75 %
Phosphorus	0,020 max. %	0,020 max. %
Sulfur	0,020 max. %	0,020 max. %
Chromium	0,8 to 1,2 %	
Molybdenum	0,15 to 0,40 %	

NOTE The actual range for each element shall be in accordance with 6.2.1 and 6.2.2, and good steel-making practice. In particular the limits specified in Table 2 take precedence over the ranges given in this table.

6.4 Heat treatment

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

6.4.2 Quenching in media other than mineral oil is permissible provided that the method produces cylinders free of cracks.

If the average rate of cooling in the medium is greater than 80 % of that in water at 20 °C without additives, every production cylinder shall be subjected to a method of non-destructive testing to prove freedom from cracks.

6.4.3 The tempering process shall achieve the required mechanical properties.

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

6.5 Testing requirements

The material of the finished cylinders shall satisfy the requirements of clauses 9, 10 and 11.

6.6 Failure to meet test requirements

In the event of failure to meet test requirements, re-testing or re-heat 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 a further heat treatment i.e. if the failure is in a test representing the prototype or batch cylinders, test failure shall require re-heat treatment of all the represented cylinders prior to re-testing; however, if the failure occurs sporadically in a test applied to every cylinder, then only those cylinders which fail the test shall require re-heat treatment and re-testing.

This re-heat treatment shall consist of re-tempering or re-quenching and tempering.

Whenever cylinders are re-heat 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 cylinders of the batch shall be rejected.

- 2) If the failure is due to a cause other than the heat treatment applied, all defective cylinders shall be either rejected, or repaired by an approved method. Provided that the repaired cylinders pass the test(s) required for the repair, they shall be re-instated 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 stress (R_e) of the material.

7.1.2 For calculation purposes, the value of R_e shall not exceed 0,9 R_g .

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 Limitation on tensile strength

7.2.1 Where there is no risk of hydrogen embrittlement the maximum value of the tensile strength is limited by the ability of the steel to pass the requirements of clause 9 and clause 10, but in no case shall the actual maximum tensile strength R_m exceed 1 100 MPa for chrome-molybdenum steels or 1 030 MPa for carbon-manganese steels.

7.2.2 Where there is a risk of hydrogen embrittlement (see ISO 11114-1) the maximum value of the tensile strength as determined in 10.2 shall either be 880 MPa or, where the ratio $R_{ea}:R_m$ does not exceed 0,9, shall be 950 MPa.

NOTE Test methods to optimize the strength levels of steels for hydrogen service are under consideration.

7.3 Calculation of cylindrical shell thickness

The guaranteed minimum thickness of the cylindrical shell (a') shall not be less than the thickness calculated using equations (1) and (2), and additionally condition (3) shall be satisfied.

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

where the value of F is the lesser of $\frac{0,65}{R_e/R_g}$ or 0,85

$R_e:R_g$ shall not exceed 0,9.

NOTE Regional International agreements may limit the magnitude of the 'F' factor used for design.

The wall thickness shall also satisfy the formula

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

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

The burst ratio shall be satisfied by test

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

NOTE It is generally assumed that $p_h = 1,5 \times$ service pressure for permanent gases for cylinders designed and manufactured in accordance with this part of ISO 9809.

7.4 Calculation of convex ends (heads and bases)

7.4.1 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 $0,075 D$

$$b \geq 1,5 a \text{ for } 0,40 > H/D \geq 0,20$$

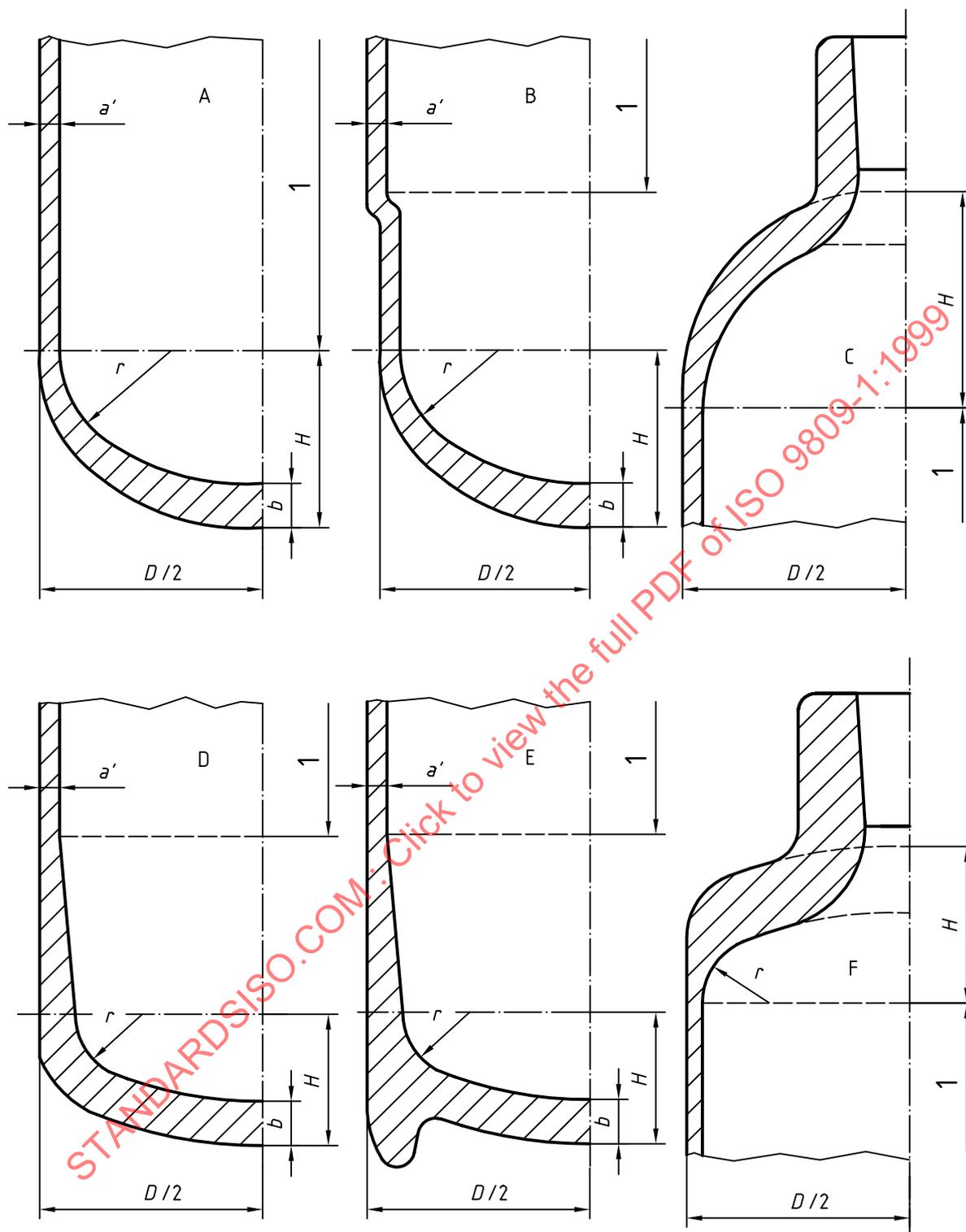
$$b \geq a \text{ for } H/D \geq 0,40$$

In order to obtain a satisfactory stress distribution in the region where the end joins the shell any thickening of the end that may be 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 line indicating dimension H in Figure 1.

Shape B shall not be excluded from this requirement.

7.4.2 The cylinder manufacturer shall prove by the pressure cycling test detailed in 9.2.3 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

7.5 Calculation of concave base ends

When concave base ends (see Figure 2) are used the following design values are recommended:

$$a_1 \geq 2a$$

$$a_2 \geq 2a$$

$$h \geq 0,12 D$$

$$r \geq 0,075 D$$

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

In order 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.

The cylinder manufacturer shall in any case prove by the pressure cycling test detailed in 9.2.3 that the design is satisfactory.

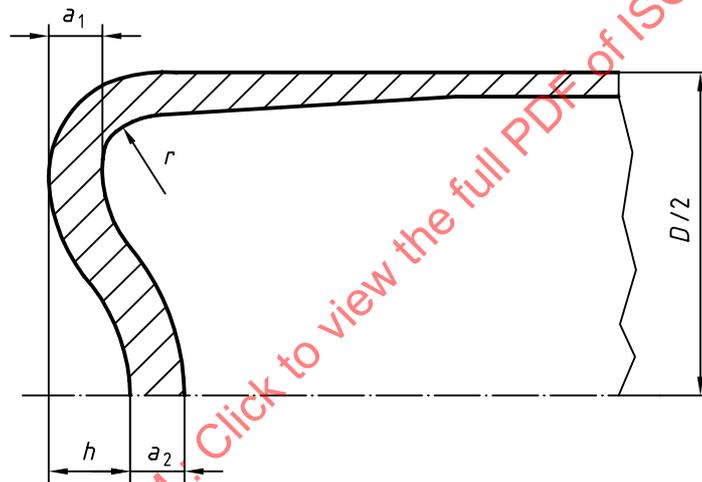


Figure 2 — Concave base ends

7.6 Neck design

7.6.1 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 may vary according to the diameter of thread, the form of thread and the sealant used in the fitting of the valve. (For guidance on torques see ISO 13341).

7.6.2 In establishing the minimum thickness, consideration shall be given to obtaining a thickness of wall in the cylinder neck which will prevent permanent expansion of the neck during the initial and subsequent fittings of the valve into the cylinder without support of an attachment such as a neck ring.

7.7 Foot-rings

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

7.8 Neck-rings

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

The manufacturer shall ensure that the axial load to remove the neck-ring is greater than $10 \times$ the weight of the empty cylinder, and that the torque to turn the neck ring is greater than 100 Nm.

7.9 Design drawing

A fully dimensioned drawing shall be prepared which includes the specification of the material.

8 Construction and workmanship

8.1 General

The cylinder shall be produced by

- a) forging or drop forging from a solid ingot or billet; or
- b) manufacturing from seamless tube; or
- c) pressing from a flat plate.

Metal shall not be added in the process of closure of the end.

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 defects

The internal and external surfaces of the finished cylinder shall be free from defects which would adversely affect the safe working of the cylinder. See annex A for examples of defects and guidance on their evaluation.

8.4 Ultrasonic examination

Each cylinder shall be ultrasonically examined for defects in accordance with annex B.

Examination of cylinders to be used for embrittling gases shall be carried out at the completion of cylinder manufacture. For cylinders containing other gases examination may be carried out either during or at the completion of manufacture. However the ultrasonic examination shall be performed on the cylindrical part after the final wall thickness has been achieved. For small cylinders with a cylindrical length of less than 200 mm or where the product of $p_w \times V < 400$ (for $R_m \geq 650$ MPa) or $p_w \times V < 800$ (for $R_m < 650$ MPa) the ultrasonic test is not necessary.

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.

8.6 Mean diameter

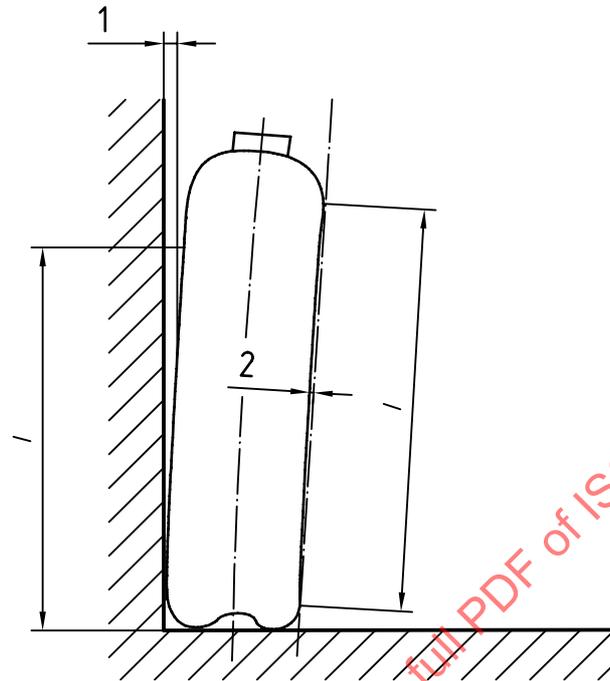
The mean external diameter of the cylindrical part outside the transition zones on a cross section shall not deviate more than ± 1 % from the nominal design diameter.

8.7 Straightness

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

8.8 Verticality

Deviation from vertical shall not exceed 10 mm per metre length (see Figure 3).



Key

- 1 Maximum $0,01 \times l$ (see 8.8)
- 2 Maximum $0,003 \times l$ (see 8.7)

Figure 3 — Illustration of deviation of cylindrical part of shell from a straight line and from vertical

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 and heat treatment, 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:

- a) it is manufactured in a different factory; or
- b) it is manufactured by a different process (see 8.1); or
- c) it is manufactured from a steel of different specified chemical composition range as defined in 6.2.1; or
- d) it is given a different heat treatment beyond the limits stipulated in 6.4; or
- e) the base or the base profile has changed e.g. concave, convex, hemispherical or also if there is a change in base thickness/cylinder diameter ratio; or
- f) the overall length of the cylinder has increased by more than 50 % (cylinders with a length:diameter ratio less than three shall not be used as reference cylinders for any new design with this ratio greater than three); or
- g) the nominal outside diameter has changed; or
- h) the design wall thickness has changed; or

- i) the hydraulic test pressure 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); or
- j) the guaranteed minimum yield stress (R_e) and/or the guaranteed minimum tensile strength (R_g) have changed.

9.2 Prototype tests

9.2.1 A minimum of 50 cylinders which are guaranteed by the manufacturer to be representative of the new design shall be made available for prototype testing. However, if for special applications the total number of cylinders required is less than 50, enough cylinders shall be made to complete the prototype tests required, in addition to the production quantity.

9.2.2 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;
- the thicknesses of the walls and ends on two cylinders (those taken for mechanical testing) meets the requirements of 7.3 to 7.6, the measurements being taken at least at three transverse sections of the cylindrical part and on a longitudinal section of the base and head;
- the requirements of clause 6 (Materials) are complied with;
- the requirements of 7.7, 7.8 and 8.5 to 8.8 inclusive are complied with for all cylinders selected by the inspector;
- the internal and external surfaces of the cylinders are free of any defect which might 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;
- the tests specified in 9.2.3 (pressure cycling test) on three cylinders, the cylinders bearing representative stamp markings.
- for cylinders made from seamless tube the test specified in 9.2.4 (base check) on the two cylinders selected for mechanical testing.

9.2.3 Pressure cycling test

This test shall be carried out 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 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 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 in order 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 exceed that specified on the drawings by more than 15 %.

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

9.2.4 Base check (for cylinders made from tube only)

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

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.

In no case shall the sound thickness (i.e. the thickness with no defects) in the base centre be less than the minimum specified thickness (see 7.4.1).

9.3 Type approval certificate

If the results of the checks according to 9.2 are satisfactory, the inspector shall issue a type approval certificate a typical example of which is given in annex C.

10 Batch tests

10.1 General requirements

10.1.1 All tests for checking the quality of the gas cylinder shall be carried out on material from finished cylinders.

For the purpose of 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;
- certificates showing the ultrasonic testing results;
- a list of the cylinders, stating serial numbers and stamp markings as required;
- confirmation that threads have been checked properly in accordance with gauging requirements. The gauges to be used shall be specified (eg ISO 11191).

10.1.2 During batch testing, the inspector shall:

- ascertain that the type approval certificate has been obtained and the cylinders conform to it;
- check whether the requirements set out in clauses 6, 7 and 8 have been met and in particular check by an external and, if physically possible, internal visual examination of the cylinders whether their construction and the checks carried out by the manufacturer in accordance with 7.7, 7.8 and 8.2 to 8.8 are satisfactory. The visual examination shall cover at least 10 % of the cylinders submitted. However, if an unacceptable defect is found (for examples see annex A), 100 % of the 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 manufacturer shall agree which tests are to be carried out;
- check whether the information supplied by the manufacturer and referred to in 10.1.1 is correct; random checks shall be carried out;

— assess the results of hardness testing specified in 11.3.

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

a) On one cylinder

— one hydraulic bursting 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 or one flattening test (see 10.3.2) or one ring flattening test (see 10.3.3);

— three impact tests in transverse or longitudinal direction as required in 10.4 when the thickness of the cylinder permits the machining of a test piece at least three millimetres thick.

For location of test pieces, see Figure 4.

The cylinder for taking the tensile and impact tests may optionally be that used in the bursting test option or the cylinder used for the flattening test option. If either the bend or ring flattening test options are chosen then the test cylinder may be that used in the burst test. The location of each test specimen shall be chosen to avoid interference with the deformed parts of the cylinder.

10.2 Tensile test

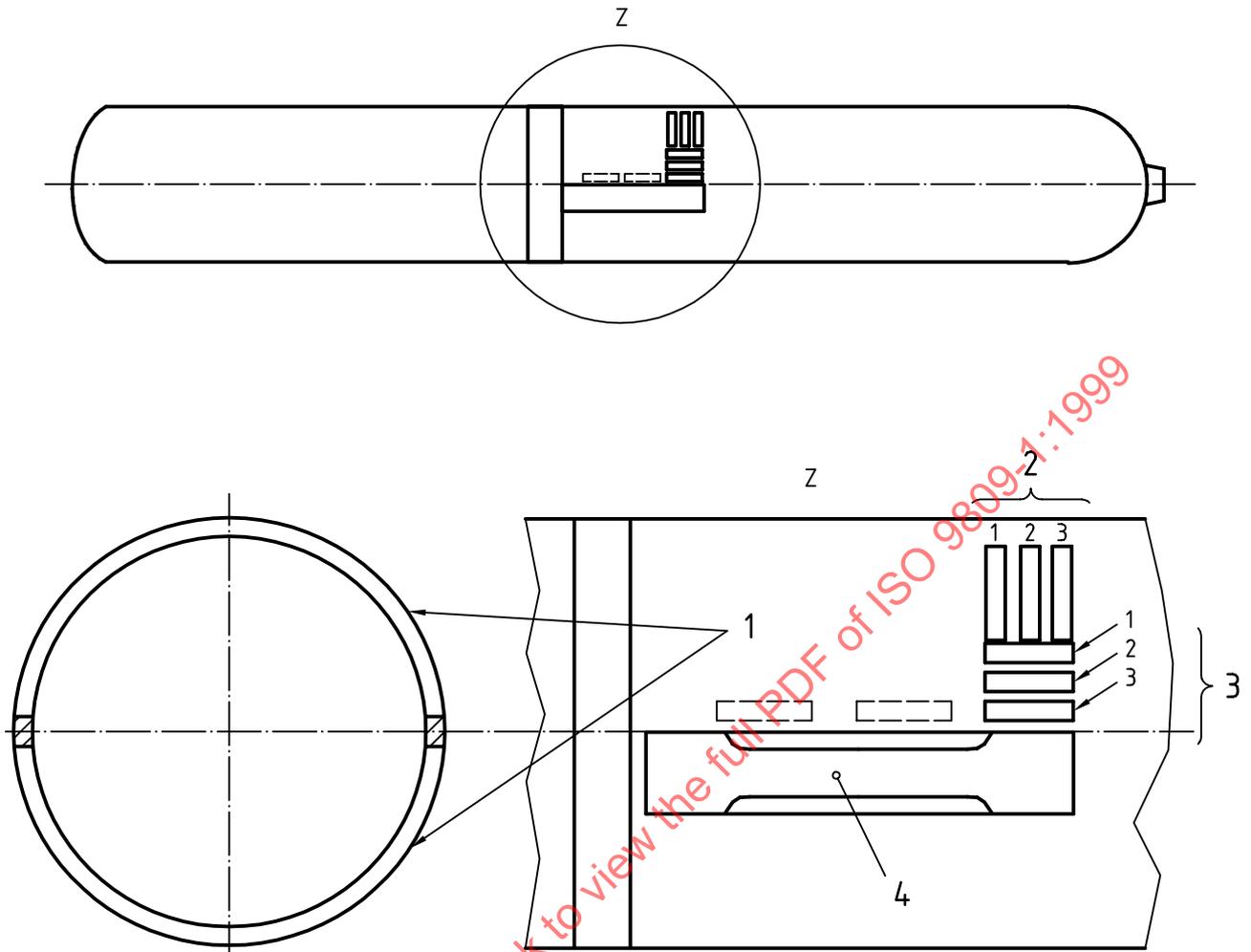
10.2.1 A tensile test shall be carried out on material taken from the cylindrical part of the cylinder by adopting either of the following procedures.

a) Rectangular specimens shall be prepared in accordance with Figure 5 and with a gauge length $L_0 = 5,65 \sqrt{S_0}$. The two faces of the test piece representing the inside and outside surfaces of the cylinder shall not be machined. The elongation (A) measured shall not be less than 14 %.

b) Machined round specimens shall be prepared having the maximum diameter practicable, the elongation (A) measured on a gauge length of $5 \times$ the specimen diameter being no less than 16 %. It is recommended that 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.

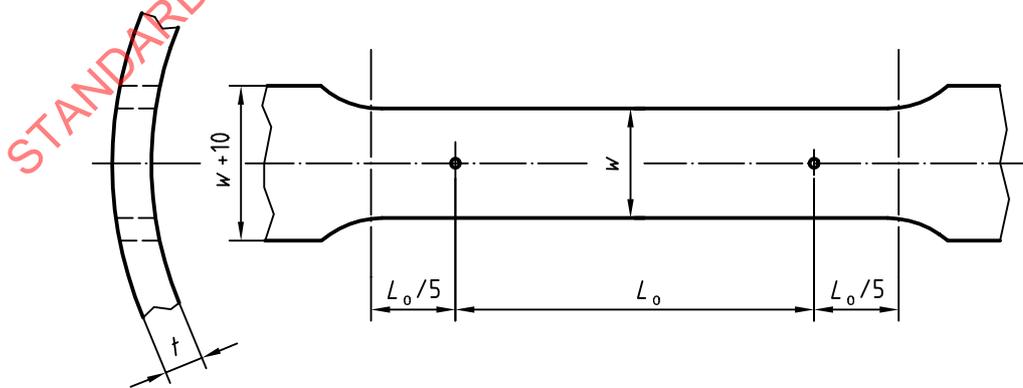
NOTE Attention is drawn to the method of measurement of elongation described in ISO 6892, particularly in cases where the tensile test piece is tapered, resulting in a point of fracture away from the middle of the gauge length.



Key

- 1 Bend test pieces or flattening ring
- 2 Transverse impact pieces
- 3 Longitudinal impact test piece (alternative positions shown dotted)
- 4 Tensile test pieces

Figure 4 — Location of test pieces



$w \leq 4t$

$w < D/8$

Figure 5 — Tensile test piece

10.3 Bend test and flattening test

10.3.1 Bend test

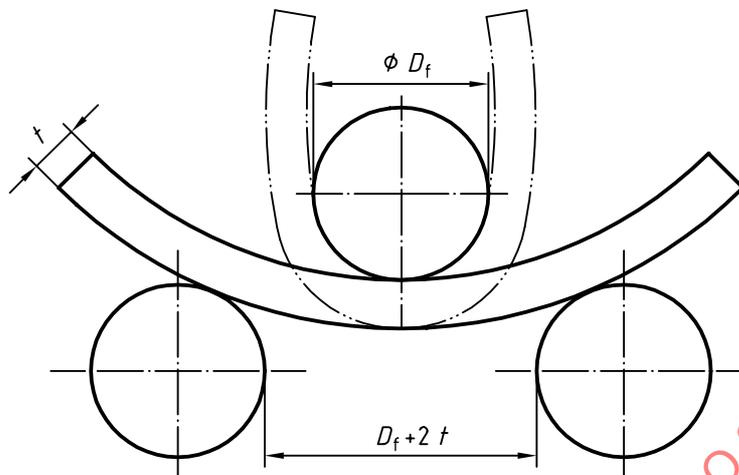


Figure 6 — Illustration of bend test

10.3.1.1 The bend test shall be carried out in accordance with ISO 7438 on two test pieces obtained by cutting either one or two rings of width 25 mm or 4 t, whichever is greater, into equal parts. 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 no further apart than the diameter of the former (see Figure 6).

10.3.1.3 The diameter of the former (D_f) shall be established from Table 4.

For the actual tensile strength (R_m) given in Table 4, D_f = n × test piece thickness (t).

10.3.2 Flattening test

10.3.2.1 The flattening test shall be performed on one cylinder selected from each batch after heat treatment.

10.3.2.2 The test cylinder shall be flattened between 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 not be 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 4. The flattened cylinder shall remain visually uncracked.

Table 4 — Bend test and flattening test requirements

Actual tensile strength R _m MPa	Bend test Value of n	Flattening test (cylinder or ring) Value of u ^a
R _m ≤ 800	4	6
800 < R _m ≤ 880	5	7
880 < R _m ≤ 950	6	8
950 < R _m ≤ 1 100	7	9

^a Distance between knife edges or platens = u × t_m, where t_m is the average cylinder wall thickness at the position of testing.

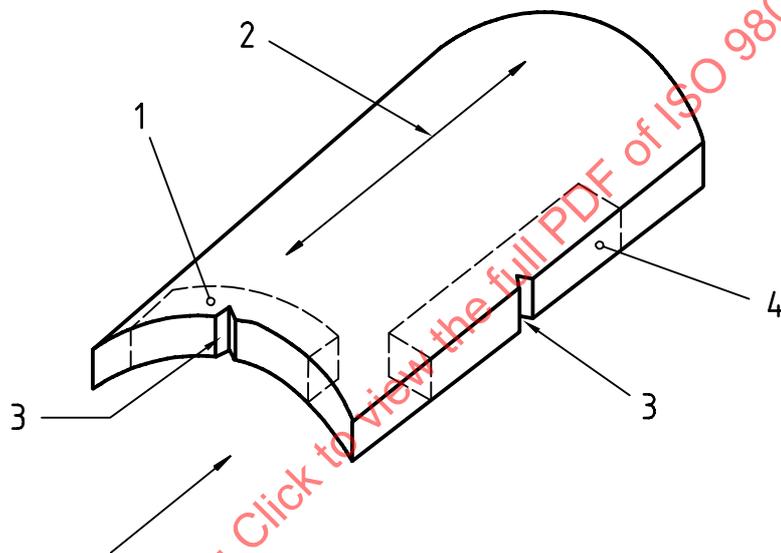
10.3.3 Ring flattening test

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

10.4 Impact test

10.4.1 Except for the requirements set out below, the test shall be carried out in accordance with ISO 148.

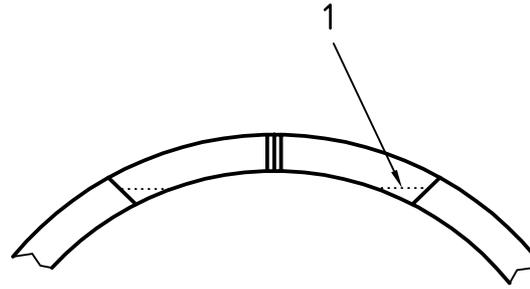
The impact test pieces shall be taken in the direction as required in Table 5 from the wall of the cylinder. The notch shall be perpendicular to the face of the cylinder wall (see Figure 7). For longitudinal tests the test piece shall be machined all over (on six faces). If the wall thickness does not 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.



Key

- 1 Transverse specimen
- 2 Cylinder longitudinal axis
- 3 Charpy V-notch perpendicular to the wall
- 4 Longitudinal specimen

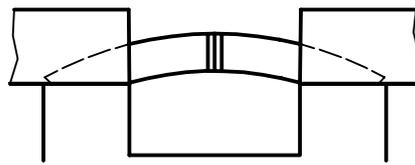
Figure 7 — Description of transverse and longitudinal impact test pieces



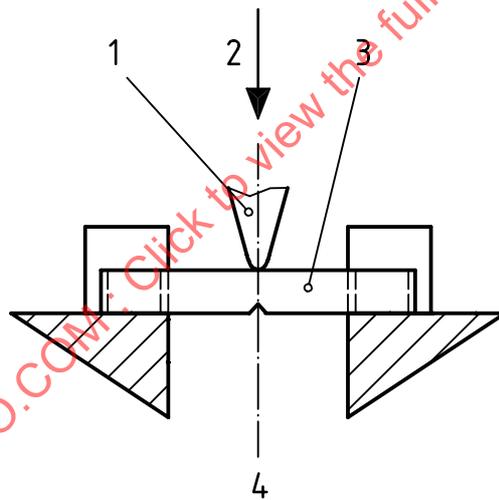
Key

- 1 Machining optional

a) Test piece taken from cylinder wall



b) Front view of test piece in impact tester



Key

- 1 Striking anvil
- 2 Direction of strike
- 3 Test piece
- 4 Centre of strike

c) Top view of test piece in impact tester

Figure 8 — Description of transverse impact testing

10.4.2 Minimum acceptance values are given in Table 5.

Table 5 — Impact test acceptance values

Cylinder diameter D , mm	> 140			≤ 140
Direction of testing	transverse			longitudinal
Width of test piece, mm	3-5	> 5 - 7,5	> 7,5 - 10	3 to 10
Test temperature, °C ^a	– 50			– 50
Mean of 3 specimens	30	35	40	60
Impact strength, J/cm ²				
Individual specimen	24	28	32	48
^a For applications at lower temperatures the test shall be carried out at the lowest temperature specified.				

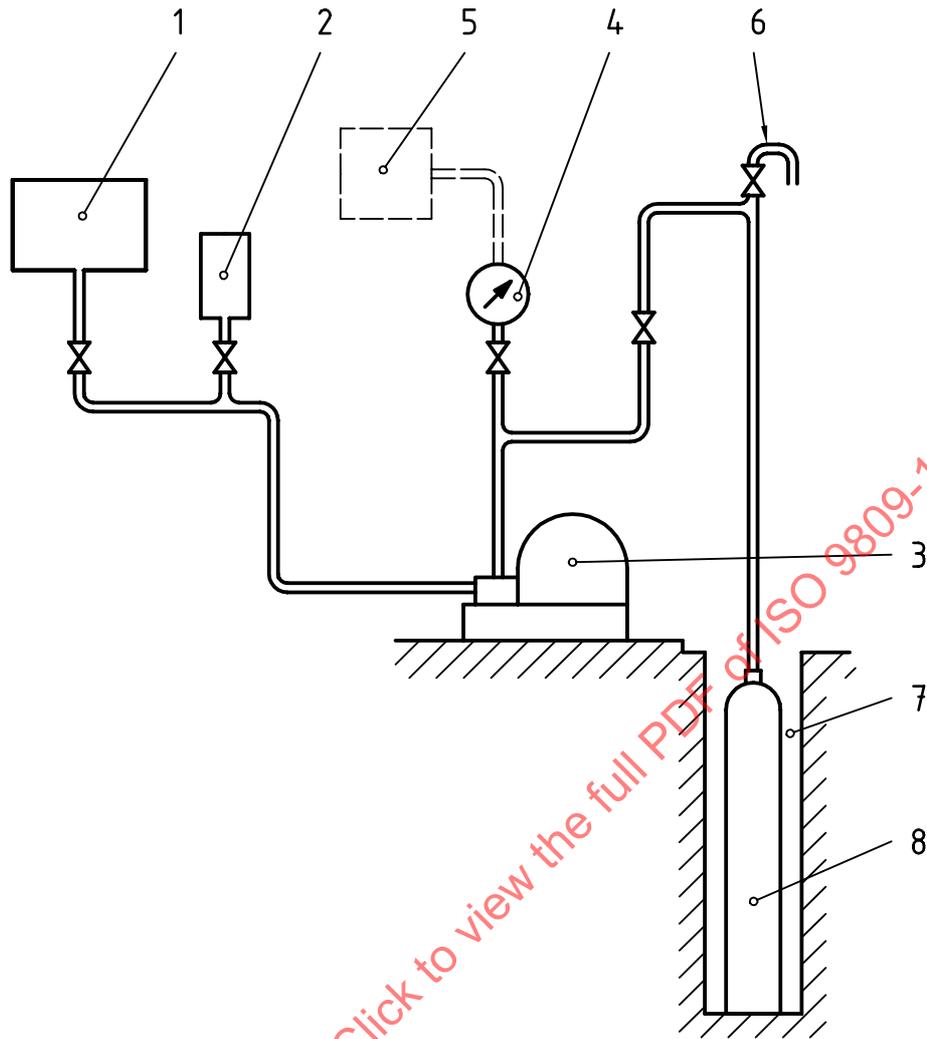
10.5 Hydraulic bursting test

10.5.1 Test installation

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

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

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Key

- 1 Test fluid reservoir
- 2 Tank for measurement of test fluid
(the test fluid reservoir may 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 bursting 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 means of 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:

- examination of the pressure/time curve or pressure/volume-of-water-used curve, to permit determination of the pressure at which plastic deformation of the cylinder commences, together with the bursting pressure;
- examination of the burst tear and of the shape of its edges.

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

- The observed yield pressure, p_y , shall be greater than or equal to $\frac{1}{F} \times$ the test pressure, i.e. $p_y \geq \frac{1}{F} \times p_h$.
- The actual burst pressure, p_b , shall be greater than or equal to $1,6 \times$ 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.

10.5.3.5 For cylinders with wall thickness less than 7,5 mm, the fracture shall be acceptable only if it conforms to one of the following descriptions:

- longitudinal, without branching (Figure 10);
- longitudinal, with side branching at each end which in no case extends beyond the longitudinal plane normal to the fracture plane (Figure 11).

10.5.4 Acceptance criteria

Figure 10 and Figure 11 illustrate satisfactory burst test profiles, and batches represented by such results shall be accepted.

If the configuration of the fracture does not conform to Figure 10 or Figure 11, but all other material and mechanical tests are satisfactory, investigation of the cause of the non-conformity shall be undertaken prior to acceptance or rejection of the batch.

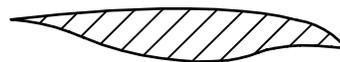


Figure 10 — Acceptable burst profiles — longitudinal without branching

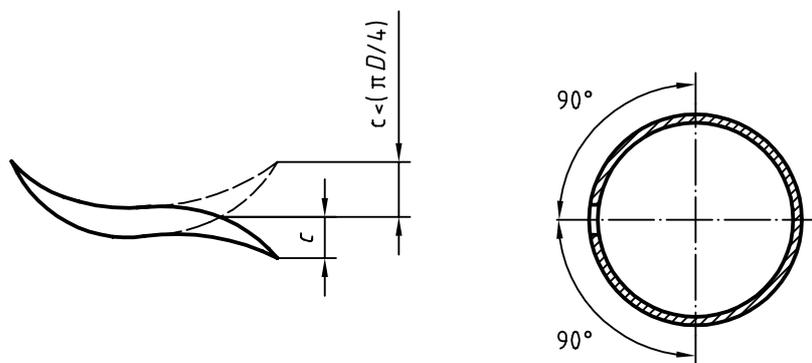


Figure 11 — Acceptable burst profiles — longitudinal with side branching

11 Tests on every cylinder

11.1 General

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

Following 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 purchaser and manufacturer shall agree which of these alternatives shall be carried out;
- a hardness test in accordance with 11.3;
- a leak test in accordance with 11.4;
- 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.

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.

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.

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 remeasured.

The cylinder shall be rejected if it shows permanent expansion (i.e. 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. total expansion less permanent expansion) under the test pressure can be established for each cylinder.

11.3 Hardness test

A hardness test in accordance with ISO 6506 (Brinell), ISO 6508 (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 Methods for measuring the surface indentations other than given in ISO 6506 or ISO 6508 may be used subject to agreement between the parties concerned.

11.4 Leak test

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

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 inspecting authority's representative to the effect that the cylinders meet the requirements of this part of ISO 9809 in all respects. An example of a suitable worded certificate is given in annex D.

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 in accordance with the regulations of the relevant statutory authority.

13 Marking

Each cylinder shall be stamped 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 or the relevant marking requirements of the countries of use.

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Annex A (informative)

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

A.1 Introduction

Several types of defect can occur during the manufacturing of a seamless steel gas cylinder.

Such defects can be mechanical or material. They can be due to the basic material used, the manufacturing process, heat treatments, manipulations, necking, machining or marking operations and other circumstances during manufacture.

The aim of this annex is to identify the manufacturing defects most commonly met and to provide general guidelines to the inspectors that perform the visual inspection. Nevertheless extensive field experience, good judgment and independence from production are necessary by the inspector to detect and to be able to evaluate and judge a defect at the time of the visual inspection.

A.2 General

A.2.1 It is essential to perform the visual internal and external inspection in good conditions.

- The surface of the metal and in particular of the inner wall shall be completely clean, dry and free from oxidation products, corrosion, scale etc. since these could obscure other more serious defects. Where necessary, the surface should be cleaned under closely controlled conditions by suitable methods before further inspection.
- Appropriate sources of illumination with sufficient intensity should be used.
- After the cylinders have been closed and the threads have been cut, the internal neck area should be examined by means of an introscope, dental mirror or other suitable appliance.

A.2.2 Small defects may be removed by local dressing, grinding, machining, or other appropriate method.

Great care should be taken to avoid introducing new injurious defects.

After such a repair the cylinders should be re-examined.

A.3 Manufacturing defects

The most commonly found manufacturing defects and their definitions are listed in Table A.1.

Rejection limits for repair or reject are also included in Table A.1. These rejection limits are established following considerable field experience. They apply to all sizes and types of cylinders and service conditions. Nevertheless, some customer specifications, some types of cylinder or some special service conditions can require stronger conditions.

A.4 Rejected cylinders

- a) All rejected cylinders should be rendered unserviceable for their original application.
- b) It may be possible to produce cylinders for different service conditions from rejected cylinders.

Table A.1 — Manufacturing defects

Defect	Description	Conditions for rejection and/or actions	Repair/Reject
Bulge	Visible swelling of the wall	All cylinders with such a defect	Reject
Dent (flats)	A depression in the wall that has neither penetrated nor removed metal (see Figure A.1) (see also excessive grinding or machining).	<ul style="list-style-type: none"> – when the depth of the dent exceeds 2 %^a of the external diameter of the cylinder; – when the depth of the dent is greater than 1 mm and when the diameter of the dent is less than $30 t \times$ its depth.^a 	Reject Permit repair
Cut, gouge, metallic or scale impression	An impression in the wall where metal has been removed or redistributed (due basically to the introduction of foreign bodies on the mandrel or matrix during extrusion or drawing operations).	<ul style="list-style-type: none"> – <u>inside defect</u>: if not superficial with sharp notches more than 5 % of wall thickness;^b – <u>outside defect</u>: when the depth exceeds 5 % of the wall thickness times the thickness of the cylinders. 	Reject Repair possible (see A.2.2)
Dent containing cut or gouge	A depression in the wall which contains a cut or gouge (see figure A.2).	All cylinders with such defects.	Reject
Excessive grinding or machining	Local reduction of wall thickness by grinding or machining	<ul style="list-style-type: none"> – when the wall thickness is reduced to below the minimum design thickness; – when it results in the formation of a dent. 	Reject See 'dent' above
Rib	A longitudinal raised surface with sharp corners (see figure A.3)	– <u>inside defect</u> : if height or depth exceeds 5 % of wall thickness or if the length exceeds 10 % of the length of the cylinders;	Repair if possible or reject
Groove	A longitudinal notch (see figure A.4).	– <u>outside defect</u> : when the height or depth exceeds 5 % of the wall thickness or when the length exceeds $5 \times$ the thickness of the cylinders.	Repair if possible or reject (see A.2.2)
Lamination	Layering of the material within the cylinder wall and sometimes appearing as a discontinuity, crack, lap or bulge at the surface (see figure A.5).	<ul style="list-style-type: none"> – <u>inside defect</u>: all cylinders with such defect; – <u>outside defect</u>: all cylinders with such a defect. 	Repair if possible or reject Repair if possible or reject (see A.2.2)
Crack	Split, material separation.	<ul style="list-style-type: none"> – when not removable within thickness tolerance; – when removable within thickness tolerance. 	Reject Repair
Neck cracks	Appear as lines which run vertically down the thread and across the thread faces. (They should not be confused with tap marks = thread machining marks) (see figure A.6).	All cylinders with such defects	Reject

Table A.1 — Manufacturing defects (concluded)

Defect	Description	Conditions for rejection and/or actions	Repair/Reject
Shoulder folds and/or shoulder cracks	Folding with peaks and troughs situated in the internal shoulder area, which can propagate into the threaded area of the shoulder (see Figure A.7). Cracks can start from folds in the internal shoulder area and propagate into the cylindrical machined or threaded area of the shoulder. (Figure A.8 shows exactly where shoulder cracks start and how they propagate.)	<ul style="list-style-type: none"> – folds or cracks that are visible as a line of oxide running into the threaded portion should be removed by a machining operation until the lines of oxide are no longer visible (see Figure A.7). After machining, the whole area should be re-inspected carefully and the wall thickness verified; – if folding or lines of oxide have not been removed by machining, if cracks are still visible or if wall thickness is unsatisfactory; – folds which extend beyond the machined area and are clearly visible as open depressions where no oxides have been trapped in the metal, should be accepted provided that the peaks are smooth and the root of the depression is rounded. 	<p>Repair if possible</p> <p>Reject</p> <p>Acceptable</p>
Internal cracks in base	Splits in the metal of the bottom of the cylinder in star form.	<ul style="list-style-type: none"> – when not removable within thickness tolerance; – when removable within thickness tolerance. 	<p>Reject</p> <p>Repair</p>
"orange peel" surface	Orange peel appearance due to discontinuous metal flow.	– if sharp cracks are visible in the orange peel surface.	Acceptable for non aggressive gases
Internal neck threads damaged or out of tolerance	Neck threads damaged, with dents, cuts, burrs or out of tolerance	<ul style="list-style-type: none"> – when the design permits it, threads may be re-tapped and re-checked by the appropriate thread gauge and carefully visually re-examined. the appropriate number of effective threads shall be guaranteed; – if not repairable. 	<p>Repair</p> <p>Reject</p>
Pitting	Severe surface corrosion.	All cylinders with such defects visible after shot blasting.	Reject
Non-conformity with design drawing		All cylinders presenting such a defect	Repair if possible or reject
Neck ring not secure	Neck ring turns under application of low torque, or pulls off under low axial load. See ISO 11117 for guidance.	All cylinders presenting such a defect.	Repair possible according to approved method only
Arc or torch burns	Partial burning of the cylinder metal, the addition of weld metal or the removal of metal by scarfing or cratering.	All cylinders presenting such a defect.	Reject
<p>^a On small diameter containers these general limits may have to be adjusted. Consideration of appearance also plays a part in the evaluation of dents, especially in the case of small cylinders.</p> <p>^b Consideration of appearance and localisation (in thicker parts with lower stresses) can be taken into account.</p>			

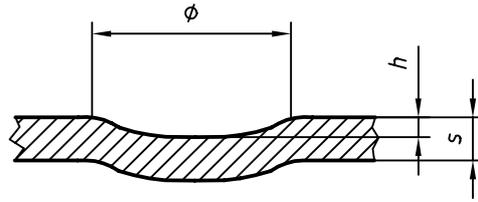


Figure A.1 — Dent

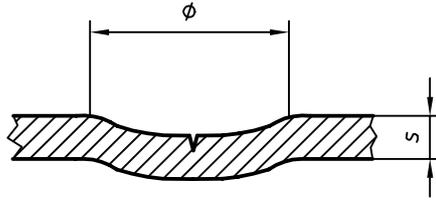


Figure A.2 — Dent containing cut or gouge

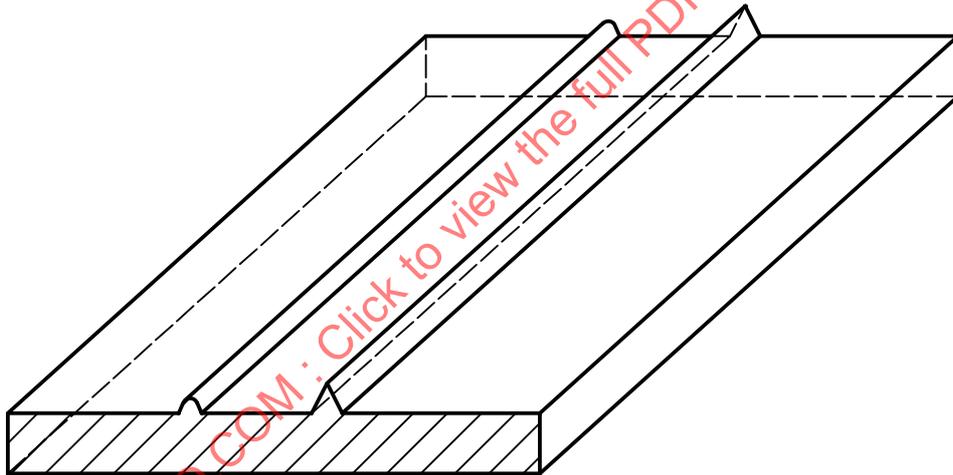


Figure A.3 — Rib

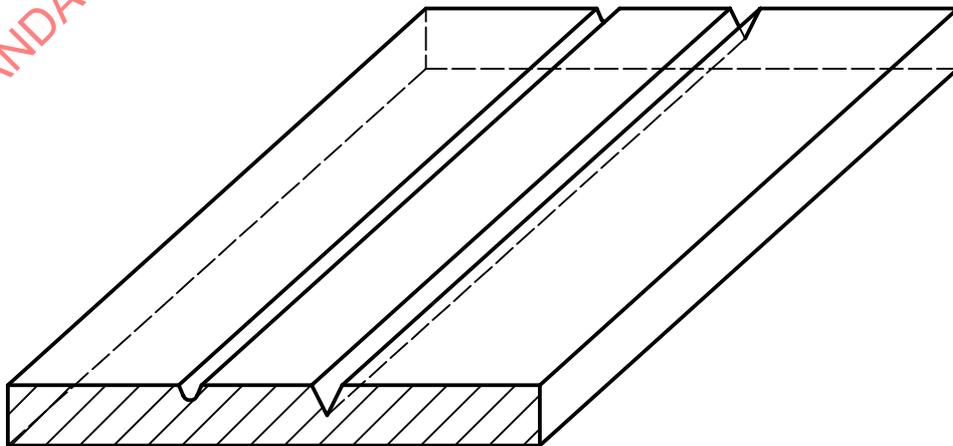


Figure A.4 — Groove

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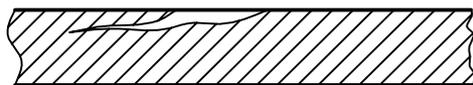
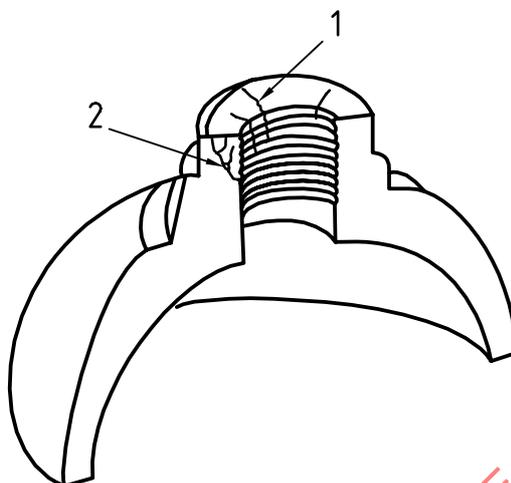


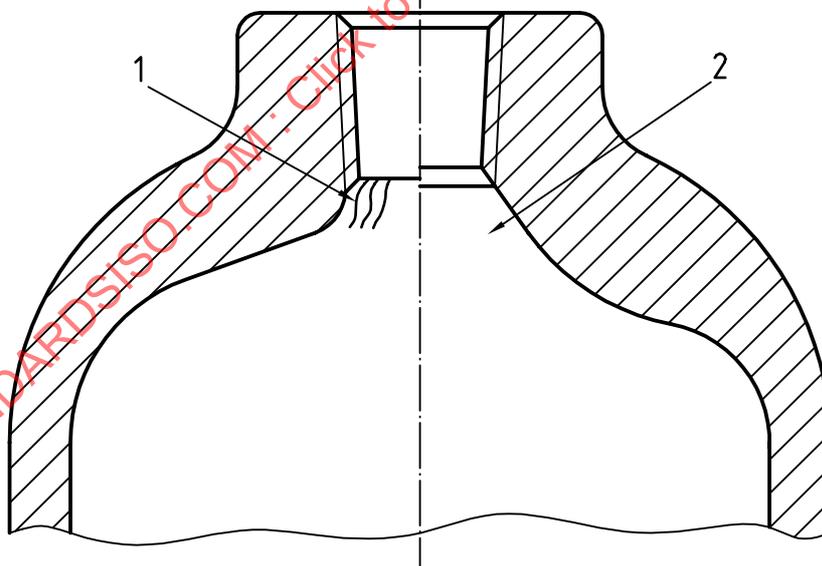
Figure A.5 — Lamination



Key

- 1 Neck cracks
- 2 Propagated crack in the neck

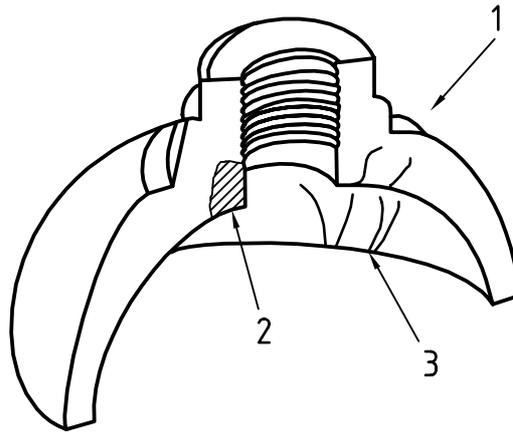
Figure A.6 — Neck cracks



Key

- 1 Folds or cracks
- 2 After machining

Figure A.7 — Cylinder shoulder folds or cracks before and after machining



Key

- 1 Shoulder cracks
- 2 Propagated crack in the shoulder
- 3 Folds

Figure A.8 — Shoulder cracks

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