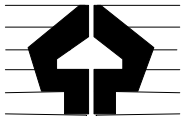

H S E
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HSE APPROVED SPECIFICATION

HSE-SS-HW3.

SPECIFICATION FOR HOOP WRAPPED COMPOSITE SEAMLESS STEEL CYLINDERS

Issue 3. **July 1999.**

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Table of contents

Scope

This specification applies to composite gas cylinders in the range 0.5 to 200 litres capacity || for the storage and transport of permanent gases except hydrogen, carbon monoxide and gases containing any free hydrogen or sulphides. Constructed in the form of a high strength seamless steel liner, the liner is overwrapped with a filament wound reinforced plastic to provide hoop reinforcement. The winding is carried out under controlled tension. The composite cylinder is pre-stressed by autofrettage to achieve a required level of stress distribution.

The composite cylinder shall be certified by a Verification Body approved by the Health and Safety Executive.

1. Definition of symbols

t	=	minimum cylinder liner wall thickness (mm)
D_o	=	external diameter of cylinder/liner (mm)
Di	=	internal diameter of cylinder/liner (mm)
P1	=	test pressure of liner (bar)
Ph	=	test pressure of composite cylinder (bar)
Po	=	operating pressure = settled pressure at 15^0 C (bar)
P	=	maximum service pressure = pressure developed by the content of a container at reference temperature (bar)
Paa	=	autofrettage pressure
Pb	=	burst pressure of the composite cylinder determined during the burst test (bar)
Pb1	=	burst pressure of the liner determined during the burst test (bar)
Pf	=	failure pressure of liner during flaw test (bar)
Py1	=	yield pressure of the liner (bar)
Pa	=	atmospheric pressure (bar)
Tk	=	minimum thickness of base at knuckle (mm)
Tc	=	minimum thickness of base in centre region (mm)
Rk	=	minimum internal knuckle radius of base (mm)
C	=	minimum concave depth of concave base (mm)
H	=	minimum outside height of domed part of convex base (mm)
Ds	=	diameter of standing circle of concave base (mm)
Ts	=	minimum thickness at junction of shoulder and neck (mm)
Tn	=	minimum thickness of neck (mm)
fe	=	maximum permissible equivalent stress (N/mm^2) at test pressure
Y	=	minimum specified yield stress (N/mm^2)
T	=	minimum specified tensile strength (N/mm^2)
Io	=	flaw length (mm)
Ic	=	total cracked length (mm)
Rc	=	flaw cutter tip radius (mm)
a	=	actual minimum wall thickness of the liner (mm)
So	=	original cross -sectional area of tensile test piece, in square millimeters, according to EN 10 002-1

2. Design

2.1. Design Criteria

2.1.1. The test pressure of the composite cylinder (Ph) shall be 1.5 times the operating pressure (Po). After autofrettage the following shall not exceed 85% of the calculated plastic (yield) stress of the liner material:

(a) The compressive stress in the liner at atmospheric pressure, and

(b) the tensile stress in the liner at test pressure of the composite cylinder.

2.1.2. The test pressure of the liner (P1) shall not be less than 50% of the test pressure of the composite cylinder and the liner design shall comply with Section **2.3** of this specification.

2.1.3. The minimum burst pressure of the liner shall be not less than 85% of the test pressure for the composite cylinder.

2.1.4. The test pressure of the composite cylinder shall not be less than the greater of:

(a) 1.5 times the specified operating pressure, or

(b) 1.18 times the intended maximum service pressure.

2.1.5. The maximum service pressure, P, is the pressure developed by the contents of a container at the reference temperature.

For design purposes the reference temperature for UK use shall be $60^{0}C$.

2.1.6. The operating pressure Po for permanent gases at the reference filling temperature of $15^{0}C$, resulting in a maximum service pressure (P) as specified above, shall be obtained by reference to British Standard 5355.

2.2. Information Required for Design Approval

2.2.1. General Information

Three copies of detailed drawings shall be prepared for design approval and submitted to the Verification Body showing each new design of a composite cylinder including dimensional details of valve threads and any other permanent features together with the method of manufacture of both the liner and the composite cylinder.

The following information shall be made available to the Verification Body:

(a) fibre strength
(b) ratio of fibre to matrix by weight
(c) tensile strength of the liner
(d) yield strength of the liner
(e) modulus of the fibre

2.2.2. Qualification Test Requirements for New Designs

No alteration shall be made to the design or the method of manufacture after approval unless such alteration has received prior agreement of the Verification Body. A cylinder shall be considered to be of a new design compared with an existing design when:

(a) it is manufactured by a different factory, or
(b) it is manufactured by a different process, or
(c) there is a change in the material of the liner or in one of the materials of the overwrap, or
(d) the liner is given different heat treatment, or
(e) the shape of base is different (concave or convex), or
(f) a change in hydraulic test pressure requires a change in wall thickness. (Where a cylinder is to be used at a lower pressure duty than that for which design approval has been given and prototype testing carried out successfully, it shall not be deemed a new design), or
(g) the overwrap is given different curing, or
(h) the nominal diameter has changed (see table 1), or
(i) the nominal length of the container has increased (see table 1).

The following Table 1 prescribes the testing requirements for the different variants. The verification body shall determine the level of reduced testing if not defined in Table 1.

Table 1

			Design Variant Changes									
Test No.	Test	New Design	Design Test Pressure ≤ 60%	Nominal Length-L		Nominal Diameter - D		Liner Design Thickness Base or Wall	Composite Thickness or Wrap Pattern	Auto frettage Pressure	Thread Change
				< 2D	>1.5L	≤ 20%	>20% <50%				
5.2.1	Pressure Test	X	X	X	X	X	X	X	X	X	
6.1.1	Liner Material	X	X		X		X	X			
6.1.3	Liner Burst	X	X		X	X	X	X			
6.2.1	Burst	X	X	X	X	X	X	X	X	X	
6.2.2	Ambient Cycle	X	X	X	X	X	X	X	X	X	
6.2.3	Salt Water Immersion	X									
6.2.4	Max. Temperature	X	X			X		X			
6.2.5	Environmental Cycle	X							X		
6.2.7	Fire Resistance	X	X		X		X				
6.2.6	High Velocity Impact	X									
6.2.8	Torque Test	X									X
6.2.9	Neck Strength	X				X	X	X			X

2.2.3. Design Particulars

The design and other particulars listed under 2.2.4 and 2.2.5 below shall be shown on or attached to the drawing.

(a) water capacities in litres
(b) list of intended contents
(c) maximum filling pressure at 15^0C
(d) composite cylinder maximum service pressure
(e) composite cylinder design test pressure
(f) liner design pressure
(g) liner minimum calculated burst pressure
(h) calculated tensile hoop stress in the liner at test pressure
(i) minimum thicknesses

2.2.4. Manufacturing, Inspection and Test particulars of the Liner

(a) materials, including limits of chemical analysis
(b) thickness and tolerances
(c) process and specification of manufacture
(d) heat treatment
(e) inspection (minimum requirements)
(f) material tests (specifications and minimum requirements)

2.2.5. Manufacturing, Inspection and Test particulars - Overwrap

(a) filament material, specification and strength test requirements
(b) filament construction, strand-geometry and treatment where applicable

(c) matrix system - main components, materials and specifications where applicable
(d) overwrap design
(e) curing process, approx. temperatures and minimum duration
(f) materials tests, specifications and minimum requirements

2.2.6 Manufacturing, Inspection and Test particulars - Complete Cylinder

(a) autofrettage pressure and approx. duration
(b) identity mark of the Verification Body
(c) proposed marking and labelling
(d) proposed periodic inspection and test procedures and rejection criteria for the type of composite cylinder

2.3. Liner design

2.3.1 General requirements

Permissible designs according to this Specification are restricted to liners having a base of concave or convex shape, head of hemispherical shape, and at least one neck opening.

2.3.2 Mechanical properties for liner design

The mechanical properties of the liner used for design (and guaranteed by the manufacturer as minimum values) shall be.

Y = 962 N/mm^2
T = 1069 N/mm^2 the corresponding ration Y/T is 0.90.

2.3.3. Design stress at test pressure of the liner

The design stress at test pressure of the liner shall be $f_e = 0{,}73Y$

2.3.4 Thickness of cylindrical body of the liner

The thickness t, shall not be less than the value given by Formula (1).

$$t = \frac{0.3P_1 \times D_0}{7f_e - 0.4P_1} \qquad \textit{formula (1)}$$

except that t shall be not less than:

$$t = 2.48\sqrt{D_i/T} \qquad \textit{formula (2)}$$

When formula (2) applies, the value of P1 shall be not less than that obtained from the transposed formula (1) putting $t = 2.48\sqrt{D_i/T}$

<u>Note:</u> Formula (1) is known as the modified Lame-Mises

2.3.5. Thickness and profile of base

(i) In order to achieve satisfactory stress distribution the transition zones from the cylindrical part where the hoop wrapping ends and the base area starts shall be tapered, the design shall be proven by passing the tests required in clause 6.2.2 of this specification.

(ii) The internal knuckle radius Rk shall not be less than 0.075 Do.

(iii) The external depth of concave C, measured from the plane through the standing circle to the external centre-base, shall be not less than 0.12 Do.

(iv) The external height of convex H shall not be less than 0.2 D0.

2.3.6. Thickness and profile of convex head (see Figure 1)

(i) The internal surface profile shall be substantially hemispherical.

(ii) Minimum thickness Ts at the junction of the shoulder and the neck-root shall be not less than 1.5t.

2.3.7 Thickness of neck (Figure 1)

Thickness of the neck Tn shall be sufficient to withstand valving and pressure-loading without permanent distortion, and in any event shall be not less than t when measured from the outside of the neck to the root of the internal thread. (See neck strength tests clause 6.2.9).

FIGURE 1. DESIGN CONFIGURATION OF LINERS

3. Materials of Construction

3.1. Liner

3.1.1 Permissible steel making process

Electric arc furnace or Oxygen process with secondary refinement. The steel shall be fine grained and aluminium killed.

3.1.2 Chemical Composition

One grade of steel only to the analysis given in Table 2.

Table 2 Steel Chemical Composition

Element	% Content by weight	
	Minimum	Maximum
Carbon	0.32	0.35
Silicon	0.15	0.3
Manganese	0.65	0.8
Phosphorus	-	0.015
Sulphur	-	0.005
Chromium	1.00	1.20
Molybdenum	0.15	0.30
Nickel	-	0.15

The combined value of micro alloying elements (V+Nb+Ti+B+Zr-N) shall not exceed 0.15% and shall be representative of good steel making practice.

The permissible deviation on product analysis from the specified range of Table 2 is given in Table 3.

Table 3 Permissible deviation on product analysis from specified range

Element	Permissible deviation %
Carbon	0.02
Silicon	0.03
Manganese	0.04
Phosphorus	0.002
Sulphur	0.002
Chromium	0.05
Molybdenum	0.03
Nickel	0.03

3.1.3. Steelmaker's Certificate

The steelmaker shall supply a certificate stating:

a) the steel making process

b) the ladle analysis ||

These certificates shall be retained by the manufacturer.

3.1.4 Mechanical properties

The following shall be obtained:

Tensile Strength (T):	1207 N/mm^2 maximum 1069 N/mm^2 minimum
Yield Strength (Y):	962 N/mm^2 minimum
Elongation on $5.65\sqrt{S_o}$:	12% minimum
Radius of bend test former:	4 x ta maximum (where ta = actual thickness)
Hardness (Brinell)	370 maximum 310 minimum

Impact strength (CVN) at -50^{0}C in accordance with Table 4.

Table 4 Charpy-V Notch Impact Values

Width of test piece mm	Longitudinal (transverse) * value J/cm^2	
	minimum	Average of 3 specimens
3 to 5	50 (33)	60 (40)
5 to 10	40 (27)	60 (33)

*Transverse impact tests shall be taken when cylinder geometry permits.

The minimum value of fracture initiation $K_{IC \text{ shall be } 93.5 \text{ N/mm}^2} \sqrt{m.}$

3.2 Overwrap

3.2.1. The filament material shall be aramide, or carbon and/or glass fibre.

3.2.2. The supplier of the filament material and of the matrix material shall provide sufficient documentation for the composite cylinder manufacturer to be able to identify fully the batch of material used in the manufacture of each cylinder.

3.2.3. The materials used shall be of uniform and consistent quality. The composite cylinder manufacturer shall verify that each new batch of materials has the correct properties and is of satisfactory quality and maintain records from which the batch of materials used for the manufacture of each cylinder can be identified.

3.2.4. Batches of material shall be identified and documented to the satisfaction of the Verification Body.

3.2.5. The filament material shall be subjected to a tensile test in accordance with the material manufacturer's specification or an identified equivalent specification accepted by the Verification Body.
The strength of acceptable fibre shall not be less than that specified on the drawing.

4. Manufacture, Heat-Treatment and Winding

4.1 Liner

4.1.1. The Liner shall be manufactured from billets using the process of hot backward extrusion followed by hot drawing, or from seamless tube, or made from plates using the process of deep drawing. ||

Closure of the cylinder to form the neck of the base when made from tube, shall be by hot spinning .

4.1.2. Heat treatment
On completion of the metal forming operations specified in Section 4.1.1, each cylinder shall be uniformly heat treated to produce the required mechanical properties.

Quenching in oil or other suitable quenchant, provided the quenching severity produced is similar to that of oils commonly used for this purpose, shall take place from an austenitising temperature between 830^0C and 900^0C, followed by tempering at a temperature between 540^0C and 680^0C.

The austenitising temperature once selected and set, shall be controlled within the limits of $\pm 10^0$C. The tempering temperature once selected and set, shall be controlled within the limits of $\pm 10^0$C.

4.1.3. The outer surface of each liner shall be protected against corrosion prior to winding with a minimum layer of zinc containing primer with a minimum film thickness of 40um.

4.2. Overwrap

4.2.1. Fibre reinforcement shall be applied to the cylinder, as indicated on the drawing of the liner, by winding fibre around it in a hoop - wrapped - pattern until the specified composite thickness is obtained.

4.2.2. The winding shall be cured by using a temperature profile which is applicable for the matrix system used.

4.2.3. The composite cylinder shall be subjected for a given time to an autofrettage pressure as specified by the manufacturer.

5. Batch testing

5.1. Liner Tests

The inspection and tests on the liner shall be carried out in such a manner as if the liner would be a cylinder on its own with the exception of the hydraulic pressure test.

For sampling purpose a "batch" is defined as number of cylinder not exceeding 202 liners of the same design, manufactured from the same cast of steel, having undergone the same heat treatment.

5.1.1. Mechanical tests

The following tests shall be carried out on a representative liner taken from a batch not exceeding 202 liners.

(1) Tensile test

One tensile test specimen shall be made from a strip cut longitudinally from a finished liner. The shape and dimensions of the test specimen shall be in accordance with Clause 6 and Annex C of EN10002-1:1990 Part 1. The cross section shall be a proportion of the wall of the liner, the face and back of the test piece comprising the liner surfaces as manufactured. The ends only of the test piece may be flattened for gripping purposes.

The tolerance on dimensions for the machined surfaces of the test piece shall be to grade IT9 of BS 4500: Part 1. The gauge length for test piece and test results shall comply with the requirements specified in Clause 8 of BS EN10002-1: 1990 Part 1.

The tensile test shall be carried out as specified in Clause 10 of BS EN10002-1: 1990 Part 1. If the thickness of the test piece, as measured over the surface of the liner is found to vary, the minimum value shall be taken for calculations.

The tensile testing machine shall be maintained to grade A of BS1610 or equivalent foreign Standards.

The results obtained for yield stress, tensile strength, and elongation shall meet the requirements of Section 3.1.4 of this Specification.

(2) Bend tests

Cold bend tests shall be made on four strips cut from the liner. The strips shall be taken from a ring (or two rings if one is insufficient) cut from the liner. The width of the test specimens shall be 25mm or four times the design thickness of the liner (including any corrosion allowance) whichever is the greater.

The test pieces shall not be machined on the surfaces corresponding to the outside of the liner, but the cut edges may be rounded off to a radius approximately 0.25 times the thickness of the test specimen.

The test specimens shall be bent round a forming tool of radius not greater than that given in Section 3.1.4 until the gap between the ends of the specimen is not greater than twice the forming tool. The face of the test specimen which corresponds to the outside surface of the liner shall be in tension during the test and shall remain uncracked.

Note: The diameter of the rolls supporting the test piece and the distance between them may be varied to suit the specimens being tested in order that the radius of curvature of the specimen may be made to correspond with that of the forming tool.

(3) Impact tests

Three longitudinal and three transverse Charpy V-notch specimens shall be prepared and tested at -50^0C in accordance with the requirements of BS131: Part 2: 1972. Transverse test pieces shall be taken only when liner wall thickness and diameter permits. Results of tests shall meet the requirements of Section 3.1.4 Table 3 of this Specification.

5.1.2 Hydraulic burst test

A hydraulic burst test shall be carried out on a representative liner taken from a batch not exceeding 202 liners.

The test shall be carried out as follows:
The rate of pressurisation shall not exceed 5 bar/second. In the course of the test, the yield pressure, burst pressure, burst mode, and volumetric expansion shall be recorded.

Acceptance criteria:

- The yield pressure shall be equal to or greater than 4/3 times the test pressure of the liner.
- The burst pressure shall be equal to or greater than 0.85 times the test pressure of the composite cylinder.
- The cylinder shall burst from a point within the sidewall.
- The cylinder shall remain in one piece after bursting.

5.1.3. Dimensional checks (other than thickness)

The following dimensional checks shall be carried out at the rate of four liners per batch not exceeding 202 liners:

(a) Ovality

The difference between maximum and minimum external diameters measured at any cross section on the body of the liner shall not exceed 2% of the mean external diameter at that section.

(b) Straightness

The maximum deviation of the cylindrical body of the liner from a straight line shall not exceed 3 mm per metre length.

(c) Length

The length shall be within the tolerances specified on the design drawing.

(d) Base depth of concavity

The depth of concavity shall be in accordance with that specified on the design drawing.

5.1.4. Production tests on every liner

(1) Wall thickness check

The wall thickness of every finished liner shall be checked ultrasonically using procedures specified in Appendix II to this Specification. If the wall thickness check is carried out at an earlier stage of production the check on the finished liners may be limited to areas where wall thickness reductions have taken place. Wall thickness less than the design minimum thickness specified on the design drawing shall be cause for liner rejection.

(2) End thickness check

The base and head thickness of every liner shall be checked ultrasonically using procedures specified in Appendix II to this Specification or other equivalent methods approved by the Verification Body (eg mechanical measuring). Base or head thickness less than the design minimum thickness specified on the design drawing shall be cause for liner rejection.

(3) Examination for defects

Examination for defects shall be carried out on every finished liner using ultrasonic procedures specified in Appendix II to this Specification. A defect of depth exceeding 5% of thickness or exceeding 0.25 mm, whichever is the greater, shall be cause for liner rejection. However, the defect may be removed and the examination repeated, provided the thickness is not less than that specified on the design drawing.

(4) Hardness test

Each liner after final heat treatment shall be subjected to a hardness test employing a spherical indentor in accordance with BS 240: Part 1 or equivalent testing methods.

The diameter of the ball and the applied load shall be in accordance with the requirements of the standard and shall be such as not to damage the liner.

The indentation shall be placed on the cylindrical portion of the liner. The surface of the liner shall be prepared by lightly polishing where the impression is to be placed, but the thickness of the wall shall not thereby be reduced below the minimum specified on the design drawing.

The hardness values shall be in accordance with Clause 3.1.4.

(5) Water capacity check

The water capacity of each liner shall be checked and recorded. This shall be done by weighing, by filling the liner with a calibrated volume liquid, or by other means approved by the Verification Body, in order to ensure compliance with the required water capacity in the design drawing.

(6) Visual Inspection

After removal of the oxide layer, by shot blasting or equivalent means, each finished liner shall be visually inspected, internally and externally, for flaws, surface condition, surface contour, neck threads, and stamping marks (see Clause 7).

If, in the judgement of the Verification Body a liner fails to meet the standards required by this Specification, it shall be rectified or rejected.

(7) Record of tests

A record shall be kept of all tests made at the liner manufacturer's works.

5.2 Batch tests on completed composite cylinder

5.2.1. Hydraulic proof test and Autofrettage

Each completed composite cylinder shall be subjected to a hydraulic proof test. The test pressure of the composite cylinder (Ph) shall be determined by the requirements of Clause 2.1.4.

The autofrettage may be carried out simultaneously with the hydraulic proof test. The autofrettage pressure is always higher than the test pressure of the composite cylinder and is shown on the drawing.

All rigid pipework, flexible tubing, valves, fittings and components forming the pressure system of the test equipment shall be capable of withstanding a pressure twice the maximum test pressure of the cylinder to be tested.

Pressure gauges shall comply with the requirements of industrial class 1 of BS 1780: Part 2 or equivalent standards.

They shall be tested at regular intervals, and in any case not less frequently than once a month.

The design and installation of the equipment and the cylinder connected to it shall be such as to avoid trapping air in the system.

Note: More than one cylinder may be tested at a time provided that they all have the same test pressure and that each individual test point is capable of being isolated.

The pressure shall not be exceeded by more than 3% or 10 bar, whichever is the lower.

The cylinders shall be held for a period at pressure as specified in the design drawing. During this period the pressure as registered on the test gauge shall remain constant. Under these conditions of test the cylinder(s) shall not show any sign of leakage or defects.

If there is a leakage in the pressure system it shall be corrected and the cylinder(s) retested.

The interior of each cylinder shall be thoroughly dried by a suitable method immediately after hydraulic testing. Cylinders shall not be heated above 350^0C.

5.2.2. Tightness test

The manufacturer shall apply tests appropriate to the manufacturing process to ensure that there is no leakage from the cylinder.

5.2.3. Pressure cycle and burst tests

One completed cylinder per production run of 1000 or less shall be subjected to a pressure cycle test in accordance with clause 6.2.2.

If there are no signs of leakage or failure the outcome is satisfactory and the cylinder shall be hydraulically tested to destruction in accordance with clause 6.2.1.

The result of the burst test is acceptable if the criteria of clause 6.2.1 are fulfilled. If the result of the burst test is not satisfactory a separate burst test on a virgin cylinder which has not been previously cycled shall be carried out as replacement test. If this cylinder passes the test requirements, the batch is acceptable. Additionally if the consignment of cylinders to be tested is larger than 202 further burst tests shall be carried out, namely 1 per 202 cylinders or less.

Cylinders taken from the batch which failed pressure cycle or burst test shall be rendered unserviceable for gas holding purposes, carried out by one of the methods such as:

(a) Crushing by mechanical means
(b) producing an irregular hole in the cylinder
(c) cutting up

If a cylinder fails the hydraulic cycle test or the burst test its reason should be investigated to the satisfaction of the Verification Body.

5.2.4 Dimensional checks

Each completed composite cylinder shall be examined and dimensionally checked to ensure compliance with the design specification. The following inspections shall be carried out:

(1) Visual inspection
    - surface finish
(2) Dimensional check on wrap
(3) Weight check

6. Design Qualification Tests

6.1. Liners

6.1.1. General Provisions

Design qualification testing of the liner shall be carried out in such a manner as if the liner would be considered a cylinder on its own having a test pressure equivalent to the test pressure of the liner ($P_{1)}$.

Details for definition of new liner designs see clause 2.2.2.

The pressure cycling test and the hydraulic proof test is not necessary to be carried out on the liner. The burst test shall be performed on liners which have not been cycled.

In addition to production batch testing specified in clause 5.1 the following prototype tests are required on all new liner designs.

The liners used for tests 6.1.2, and 6.1.3 shall be from the first production batch of the new design, and shall be certified by the manufacturer as being representative of that particular design and manufacturing process. The tests specified in clause 6.1.4 need only be carried out once for a given liner material with a defined heat treatment.

6.1.2. Dimension check

Longitudinal sections shall be cut from the neck and base of a liner of each new design and checked for conformity with the approved design drawing.

6.1.3. Hydraulic burst test

Two liners shall be subjected to a hydraulic burst test. The rate of pressurisation shall not exceed 5 bar/second. In the course of the test, the yield pressure, burst pressure, burst mode, and volumetric expansion shall be recorded.

Test acceptance criteria are:

- The yield pressure (Py1) shall be equal to or greater than 4/3 times the test pressure of the liner (P1).

- The burst pressure (Pb1) shall be equal to or greater than 0.85 times the test pressure of the composite cylinder (Ph).

- The liner shall burst from a point within the sidewall.

- The liner shall remain in one piece after bursting.

6.1.4 **Flawed cylinder burst test.** ***

The flawed cylinder burst test is to establish that the failure pressure (P_f) which produces the leak (not a burst) with a flaw of a given size, is greater than a mimimum pressure related to 2/3 x P1 = Ps

6.1.4.1 Flaw geometry

The flaws shall be machined longitudinally, approximately at mid-length of the cylindrical part of the cylinder. The flaws shall be located at minimum wall thickness (t) of the midsection, based on the thickness measurement at four points around the cylinder.
The flaw length l_o shall be the overall length of the cut and shall be equal to:

$$l_o = 1{,}6 \sqrt{D_o \times t}$$

The flaw cutter shall be approximately 12.5 mm thick with an angle of 45° and a tip radius of 0.25 $\pm$ 0,025 mm. The cutter diameter shall be 50 mm for cylinder with diameter D_o less than or equal to 140 mm, 65 to 85 mm for cylinders with D_o greater than 140 mm (a standard CVN cutter is recommended)

Note - The cutter should be sharpened regularly to ensure tip radius meets requirements.

The depth of the flaw shall be adjusted to obtain a leak by hydropressurisation. "Leak" means that the crack will not propagate by more than 10% outside the machined flaw measured on the external surface, i.e. total length not over 1,1 x l_o.

6.1.4.3. Test procedure.

The test shall be performed by monotonic pressurization or cyclic pressurization as described below:

-Monotonic pressurization to burst

The cylinder shall be pressurized hydrostatically as prescribed in clause 6.1.3 (hydraulic burst test) until pressure is released from the cylinder at the flaw location.

- Cyclic pressurization.

The test shall be performed at pressure Ps x (t/a) as described in clause 6.2.2 (pressure cycling tests) The initial flaw depth shall be at least 0,6 x a.

6.1.4.4 Acceptance criteria.

a) The test result is acceptable only if the following two conditions are simultaneously met:

1) Failure pressure $Pf \geq Ps \times (t/a)$

2) Failure mode is by leak

b) If the failure pressure $Pf \geq Ps \times (t/a)$ causes a leak, a further test may be performed with less deep flaw γ. In the retest condition a) shall apply.

c) If the failure pressure $Pf \leq Ps \times (t/a)$ causes a burst, a further test may be performed with a deeper flaw γ. In the retest condition a) shall apply.

d) If the failure pressure $Pf \geq Ps \times (t/a)$ causes a burst, the cylinder has failed to meet the test requirements.

6.2. Complete Cylinders

The necessary amount of completed composite cylinders shall be chosen at random by the Verification Body from the first production run of a new design and subjected to the prototype tests as described below:

6.2.1 Burst test under hydraulic pressure at ambient temperature

Three cylinders shall be submitted to this test.

Procedure:
The rate of pressurisation shall not exceed 5 bar/second. In the course of the test, the yield pressure, burst pressure and burst mode, shall be recorded.

Test acceptance criteria are:

- burst pressure (P_b): $Pb \geq 1.67\ Ph$
- burst initiation shall be by longitudinal failure in the cylindrical part and the liner shall remain in one piece

Parameters to monitor during test:

- pressure
- pressure/time curve

6.2.2. Resistance to pressure cycles at internal test pressure (Ph) at ambient temperature

Two cylinders shall be submitted to this test.

Procedure:

The cylinders shall carry stampmarkings in accordance with Section 7. The test shall be carried out using a non-corrosive pressurising fluid. The maximum pressure in the cycle shall be the test pressure of the composite cylinder (Ph). The minimum test pressure in the cycle shall not exceed 10% of the test pressure. The frequency of cycling shall not exceed 15 cycles/minute, and the temperature measured on the outside of the cylinder during the test shall not exceed 50^0 C.

Criteria:

- the cylinder shall withstand 12000 cycles to test pressure Ph without failure by burst or leakage

Special parameters to monitor:

- Pressure
- Pressure/time curve
- The temperature of the cylinder shall be monitored routinewise at least twice a day
- The water capacity shall be monitored before the test and immediately after completion of the appropriate number of cycles
- After completion of this test the cylinder shall then be destroyed.

Failure shall be construed as leakage from any part of the cylinder other than the neck/ pipework joint.

6.2.3. Immersion in Salt Water (Optional - for underwater use only)

Two cylinders shall be submitted to this test.

Procedure:

The cylinders shall be unpainted (only the liner protected from corrosion in accordance with clause 4.1.3.) but otherwise finished as for the intended application.
Two closed cylinders shall be immersed in an aqueous solution containing 35g of sodium chloride/1 at ambient conditions for 90 days.
The cylinder shall be immersed:

- for 45 days at operating pressure at 15^0C
- for 45 days without pressure

Then:

- one of the cylinders shall be submitted to a hydraulic burst test, procedure in accordance with the test described in 6.2.1.
- the other cylinder shall be submitted to pressure cycling at P_h in accordance with the test described in 6.2.2.

Criteria

- In accordance with test criteria in 6.2.1 for the first cylinder
- In accordance with test criteria in 6.2.2 for the second cylinder

6.2.4 Exposure to maximum Temperature at Test Pressure

Two cylinders shall be submitted to this test.

Procedure

The test shall run 2000 hours. The test shall be conducted at 70 ± 5^0C and humidity less than 50%
After this test, the cylinder shall be submitted to a hydraulic burst test, the procedure in accordance with test described in clause 6.2.1.

Criteria:

- burst pressure, $P_b \geq 1.67\ P_h$

6.2.5. Environmental Cycle Test

One cylinder shall be submitted to this test.

Procedure:

- Condition one cylinder for 48 hours at atmospheric pressure at the cylinder's maximum operating temperature which shall not be less than 60^0C and a relative humidity greater than or equal to 95%.
- Hydraulically apply 5000 cycles from a pressure approximately equal to atmospheric pressure (P_A) to two third of the test pressure $^2/_3$ P_h under the same conditions. Stabilise the cylinder at ambient conditions.
- Condition the cylinder at minus 50^0C
  Apply 5000 cycles from approx. atmospheric pressure (P_A) to $^2/_3$ P_h at minus 50^0C in accordance as described in 6.2.2.
- Stabilise cylinder at ambient conditions
  30 cycles from P_A to P_h at $(20 \pm 5)^0$C and then the hydraulic pressure is raised to burst pressure in accordance with clause 6.2.1.

Criteria:

- burst pressure shall be recorded and have the criteria of test described in 6.2.1 except that burst pressure: $P_b \geq 1.4\ P_h$.

*6.2.6. **High velocity impact (bullet) test** (for military purposes only)*

One cylinder shall be submitted to this test.

Procedure:

A representative cylinder charged with air or nitrogen to operating pressure shall be impacted by a 7.62 mm (0,3") calibre amour-piercing projectile having a velocity of approximately 850 m/s (2800 ft/sec). The cylinder shall be so positioned that the point of impact of the projectile is in the cylinder side wall having hoop winding, at approximately 45^0 angle and aimed to exit at the cylinder side wall
Distance from firing location to test cylinder not to exceed 45 m (50 yards).

Criteria:

- the test cylinder shall reveal no evidence of a fragmentation failure, whether or not the bullet penetrates the cylinder.

Measurements:

- approximate size of entrance and exit openings shall be recorded.

*6.2.7 **Fire Resistance Test***

This test shall apply only to those cylinders to which a pressure relief valve is fitted in service.

Two cylinders shall be submitted to this test.

- one in horizontal position
- one in vertical position

The cylinders shall be fitted with a suitable valve and filled with air or nitrogen at operating pressure (P_o) at 15^0C. The cylinders shall be placed approximately 0.1m from the top of the fire, in the case of a wood fire, or at the surface of the liquid in case of a hydrocarbon based fire. They shall be exposed to the fire until completely empty.

Procedure:

A suitable method for creating a fire is shown in Appendix A.

Criteria:

- The cylinder shall not fail during the fire test.
- Failure shall be by release of pressure in the valve.

6.2.8. Torque test

One cylinder shall be submitted to this test.

The cylinder threads shall show no permanent expansion or deformation when mated with a corresponding valve and tightened to 110% of the maximum torque recommended in EN ISO 13341.

6.2.9. Neck strength

One cylinder shall be submitted to this test.

The neck of the cylinder shall show no significant deformation and shall remain within drawing tolerance when mated with a corresponding valve and tightened to 150% of the torque recommended in EN ISO 13341.

7. Marking

Each finished composite cylinder which satisfies the requirements of this specification shall be permanently and legibly marked on the cylinder shoulder, some of the marking may be acheived by use of a printed label, placed in the resin. The following marking shall be applied:- ||

(a) the mark of this specification HSE-SS-HW3
(b) operating pressure ($P_{o)\text{ in bar units at }15}{}^{0}C$
(c) test pressure (Ph) in bar units
(d) manufacturers mark
(e) the mark of the Verification Body
(f) date (month and year of the first hydraulic pressure test)
(g) nominal water capacity in litres
(h) serial number
(i) the empty weight in kg of the composite cylinder excluding any protective coating

The layout of the marking shall be part of the approved design.

APPENDIX I

Fire test

I.1 Scope

To describe a test method for the building of a bonfire of standard proportions. To carry out these tests the operator shall wear suitable working clothes, which may include helmet and face visor.

Attention is drawn to the necessary for taking precautions to safeguard the health of personnel conducting the tests against the risk of fire and inhalation of smoke and any toxic products of combustion's.

I.2 Apparatus

I.2.1 Metal frame support, (250 ± 10) mm high, (900 ± 10) mm wide and of a length equal to that of the test fire (within the tolerance limits). The steel frame (see figure I.1) is constructed of 50 mm x 50 mm angle sections.

I.2.2 Wooden sticks, made of pinus silvestris containing, 12.5% to 17.5% of moisture by mass, and of square section of side (39 ± 2) mm. The moisture content of the sticks shall be determined using commercially available instruments which measure electrical conductivity between two needle probes pushed into the sticks.

Some variation of reading may be obtained due to structural variation of the timber and the direction of the grain. This type of instrument should therefore be calibrated in case of doubt by drying samples of the sticks at (103 ± 2) ^{0}C, but to convenient length and to constant mass, and by weighing them at 24 h intervals.

The moisture content expressed as a percentage is given by the following equation:

$$\text{Percentage moisture} = \frac{(\text{initial mass - dry mass})}{\text{dry mass}} \quad \text{x } 100$$

The wooden sticks shall be stacked in 8 layers on the metal frame(s) as shown in figures I.1.

The sticks in each layer shall be spaced at nominal 100 mm centres with nominal 61 mm gaps between the sticks.

The sticks laid transversely (layers 2, 4, 6, 8) shall have a length of (500 ± 10) mm.

The sticks laid longitudinally (layers 1, 3, 5, 7) shall have length equal to the test fire length, again with a permissible deviation of (± 10) mm.

For vertical test positions the fire size shall be 500 mm x 500 mm with tolerance of (± 10) mm.

For horizontal test positions the test fire length shall exceed that of the cylinder (including valve) by a minimum of 200 mm.

I.2.3 Lighting fuel, consisting of an aliphatic hydrocarbon having an initial boiling point of not less than 88^0C and a final boiling point of not more than 105^oC. Typical fuels meeting this requirement are heptane and certain solvent fractions sometimes referred to as commercial heptane.

I.2.4 Lighting tray, being (100 ± 10) mm longer than the nominal length of the test fire, of width of (600 ± 10) mm and depth of (100 ± 10) mm. Long lighting trays are difficult to handle, and it is convenient to use any number of smaller trays to give the required length. Arrange with no appreciable gap between the trays.

!.2.5 A suitable fire may also be created by the use of kerosene. For further information see reference standards ISO/DIS 11439, CGA C14 1992. ||

I.3 Test fire location

Locate the test fire outdoors and sheltered from draughts.

1.4 Procedure

The procedure is as follows:

a) pour water into the lighting tray(s) to form a layer at least 3 mm deep over the whole base of the tray, then add 21 of lighting fuel to give an additional approximate depth of 5 mm;

b) ignite the fuel.

FIGURE I.1: VERTICAL FIRE TEST

FIGURE I.2: HORIZONTAL FIRE TEST

APPENDIX II

Ultrasonic defect detection and thickness measurement

II.1 Defect detection

II.1.1 General

This method covers the pulse echo testing of seamless steel cylinders.

Cylinders shall be tested for defects in the parallel walls.

II.1.2 Surface condition

Both the surface and the reflecting surfaces of the cylinder shall be clean and free from any materials that will interfere with the test, eg. loose scale.

II.1.3 Equipment

The test equipment shall be of the pulse echo type and shall be capable of detecting the calibration notches to the degree required in the calibration procedure specified in II.1.6.

II.1.4 Couplant

A coupling method that ensure adequate transmission of ultrasonic energy between the testing probe and the cylinder shall be used.

II.1.5 Calibration standards

II.1.5.1 A calibration standard of a convenient length shall be prepared from a cylinder of similar diameter and wall thickness, material surface finish and metallurgical condition to the cylinder to be inspected. The calibration standard shall be free from discontinuities which may interfere with the detection of the reference notches.

II.1.5.2 A longitudinal and a transverse reference notch shall be introduced on the outer and inner surfaces of the calibration standard. The transverse and longitudinal notches may be positioned within 25 mm of each other but the pairs of notches on the inner and outer surfaces shall be separated by at least 50 mm along the axis of the standard.

The standard notches shall be 25 ± 0.25 long and their width shall not be more than twice the nominal depth. The notch depth shall be 5% of the minimum wall thickness or 0.25 mm, whichever is the greater. The tolerance on depth shall be ± 10% of the nominal notch depth. The cross section of the notch shall be nominally of rectangular section but if spark erosion methods are employed the bottom of the notch may be rounded.

II.1.6 Calibration of equipment

Using the calibration standard specified in II.1.5 the equipment shall be adjusted to produce clearly identifiable indications from inner and outer surface notches. The relative response from notches shall be as near equal as possible. The indication of smallest amplitude shall be used as the rejection level and for setting visual, electronic monitoring or recording devices.

The equipment shall be calibrated with the reference standard and/or probe moving in the same manner, in the same direction and at the same speed during the inspection of the cylinder.

II.1.7 Frequency

The ultrasonic test frequency shall be between 2 MHz and 6 MHz.

II.1.8 Procedure

The cylinder to be inspected and the search unit shall have a rotating motion and a translation relative to one another such that a helical scan of the cylinder surface will be described. The speed of rotation and translation shall be constant within ± 10%.

The pitch of the helix shall be less than the probe diameter and shall be related to the effective beam width so as to ensure 100% coverage at the speeds and feeds used during the calibration procedure.

The cylinder wall shall be tested for longitudinal defects with the ultrasonic energy transmitted in both circumferential directions and for transverse defects in both longitudinal directions.

The calibration of the equipment shall be periodically checked by passing the calibration standard through the test procedure. This check shall be carried out at time intervals of not more than 1 h or after 30 cylinders have been tested. If during this check the presence of the appropriate notch is not indicated, then all cylinders tested subsequent to the last acceptable calibration shall be retested after recalibration has been accomplished.

II.1.9 Assessment of results

Any cylinder not showing a defect indication shall be considered to have passed this ultrasonic inspection.

Note: A defect indication is one that is equal to or greater than the lesser indication of the reference notches.

If surface defects are removed by grinding than after correction the cylinder shall be resubjected to ultrasonic detect detection and thickness measurement.

Cylinders continuing to show defect indications at points of minimum design thickness shall be deemed not to comply with the requirements of this specification.

II.2 Thickness measurement

11.2.1 General

This method covers the thickness measurement of seamless cylinders employing either the pulse echo or the resonance system. Either contact or immersion techniques may be used. The cylinder shall be examined to ensure that the thickness is not below the design minimum:

(a) on the base and head;

(b) on the parallel body; and

(c) on any part of the container where surface blemishes have been removed by grinding, machining etc.

II.2.2 Surface condition

Both the testing and the reflecting surfaces of the container shall be clean and free from any materials that will interfere with the test, eg loose scale.

II.2.3 Equipment

The test equipment shall be of either the pulse echo or the resonance type and shall be capable of indicating a given thickness of material to an accuracy within ± 2.5% of the set value.

II.2.4 Couplant

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

II.2.5 Calibration standards

Where possible a calibration standard, of similar diameter, material surface finished and metallurgical condition to the cylinders under test and with a diameter machined or ground to the minimum allowable thickness shall be used. When it is not possible to provide such a calibration standard, flat calibration standards shall be used.

II.2.6 Calibration of equipment

Using the calibration standard specified in II.2.5 the equipment shall be adjusted to produce a reject signal when the indicated thickness is less than a value equal to 2.5% greater than the minimum design thickness.

The equipment shall be calibrated with the reference standard and/or probe moving in the same manner, in the same direction and at the same speed as will be used during the inspection of the cylinder.

II.2.7 Frequency

The ultrasonic test frequency used shall be not less than 2 MHz.

II.2.8 Procedure

The cylinder to be inspected and the search unit shall have a rotating motion and a translation relative to one another such that a helical scan of the container surface will be described. The speed of translation and rotation shall be constant within ± 10%. The pitch of the helix shall be less than the probe diameter and shall be related to the effective beam width so as to ensure 100% coverage at the speed and feeds used during the calibration procedure.

The cylinder shall be examined in such a manner as to check that nowhere does the thickness fall below the specified minimum allowed.

The calibration of the equipment shall be periodically checked by passing the calibration standard through the test procedure. This check shall be carried out at time intervals of not more than 1 h or after 30 cylinders have been tested. If during this check the presence of the minimum area is not indicated, then all the cylinders tested subsequent to the last acceptable calibration shall be retested after calibration has been accomplished.

II.2.9 Assessment of results

All cylinders that are not acceptable when examined on a go, no-go system shall be re-examined using equipment capable of giving an actual measurement. Any cylinders that are shown to be below the minimum wall thickness shown on the manufacturer's drawing shall be deemed not to comply with the requirements of this specification.

APPENDIX III

Periodic Examination and Testing

1. Composite cylinders to this specification shall be examined for defects externally by visual inspection at each cylinder fill, by a person having appropriate training, experience and facilities.

2. Within the period of 5 years from the date of the last hydraulic pressure test every composite cylinder to this specification shall be examined for defects externally and internally, and before continuing in service, be subjected to a hydraulic proof pressure test in accordance with an appropriate standard and the manufacturers recommended procedure, by the manufacturer or an organisation authorised to test composite cylinders on behalf of the manufacturer.

3. The procedure for external and internal inspection shall be specified by the manufacturer, including the appropriate damage identification criteria for the acceptance or rejection of cylinders for further service. This procedure may refer to relevant guidance published by the Compressed Gas Association in the USA (CGA Pamphlet C-6.2) and the relevant sections of BS 5430: Part 1: in respect of non wrapped and internal surfaces, excluding any method of cleaning or surface preparation that might damage the composite.

4. A cylinder with superficial damage only, deemed by the competent person, not to have any adverse effect on its safety and integrity, may continue in service.

5. Cylinders with minor damage below the rejection level in accordance with the criteria specified under para. 3 of this Appendix including minor flaws in the reinforcement that may be repaired, shall be returned to the manufacturer for examination or repair and subjected to a hydraulic proof pressure test in accordance with the manufacturers recommended procedure.

6. Cylinders shall be rejected if they do not meet hydraulic proof pressure criteria or if any flaw has grown following repair and testing.

7. Rejected cylinders shall be rendered unserviceable from holding gas under pressure.

8. In the event of doubt or dispute in connection with para. 4 of this Appendix, the manufacturer, and if necessary, the Verification Body shall be consulted.

9. 15 years from the date of the first hydraulic pressure test each composite cylinder shall be returned to the manufacturer for re-assessment of its suitability for further service. They may continue in service for a further period of up to 15 years only with the written consent of the manufacturer and the Health and Safety Executive.

10. Records of all periodic examinations and testing shall be held together with materials and test certificates and inspection reports relating to the manufacture of the cylinder, for the lifetime of the cylinder.