SPECIFICATION FOR FULL-WRAPPED

COMPOSITE ALUMINIUM ALLOY GAS CYLINDERS

HSE-AL-FWI

Issue 1 - January 1991

Application

This specification applies to composite gas cylinders in the range 0.5 to 150 litres water capacity for the storage and transport of compressed or liquefiable gases, constructed in the form of a seamless aluminium alloy liner overwrapped with filament reinforced plastic to provide longitudinal and circumferential reinforcement and the composite cylinder pre-stressed by autofrettage to achieve a required level of stress distribution.

The composite cylinders shall be used for containing air, nitrogen or oxygen, in a compressed state, in breathing apparatus or emergency equipment, including inflating apparatus, for the purpose of rescue, fire fighting and similar operations or related training.

The composite cylinder shall be certified by a Verification Body approved by the Health and Safety Executive. The verification of compliance with the specification shall as shown in Appendix II and III.

1. DESIGN

Design Criteria

1.1 After autofrettage, the compressive stress in the sidewall of the liner at atmospheric pressure shall not exceed 95% of the minimum yield strength of the aluminium as determined in Clause 3.2.4. The maximum tensile stress in the liner sidewall at 2/3 test pressure shall not exceed 60% of the minimum yield strength.

1.2 The maximum filament stress at 2/3 test pressure shall not exceed 30% of the calculated filament stress at the virgin burst pressure of the batch test cylinder.

1.3 The end designs shall incorporate added materials to assure the stresses in these areas are less than the stresses found in the cylindrical portion.

1.4 Stresses shall be computed from computer code NASA CR-72124 "Computer Program For the Analysis of Filament-Wound Reinforced Metal Shell Pressure Vessels" May 1966, or other approved analysis techniques.

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

(a) 1.5 times the specified filling pressure, or

(b) 1.18 times the intended maximum service pressure.

1.6 The maximum service pressure, p, is the pressure developed by the contents of a container at the reference temperature, tp.

For design purposes the reference temperature for UK use shall be:

for permanent gases	60°C
for high pressure liquefiable gases	52.5°C
for carbon-dioxide in containers fitted with safety devices	50°C

1.7 The filling pressure for permanent gases and filling ratios for liquefiable gases at the reference filling temperature of 15°C resulting in a maximum service pressure as specified above, shall be obtained by reference to British Standard 5355.

1.8 Only parallel threads shall be used to accommodate valve fittings.

1.9 **Information Required for Design Approval**

General Information

1.9.1 Three copies of detailed drawings shall be prepared for design approval and submitted to the Verification Body showing each new design of 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 design and other particulars listed under 1.9.3 and 1.9.4 below shall be shown on or attached to the drawings.

1.9.2 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 approved design, when

(a) it is manufactured by a different factory, or

(b) it is manufactured by a different process, or

(c) there is change in the material of the liner or in one of the

(d) materials of the overwrap, or

(e) the liner is given different heat-treatment, or

(f) the overwrap is given different curing, or

(g) the diameter has changed by more than 10%, or

(h) the length of the container has increased by more than 50%, or

(i) the water capacity has changed by 30% or more, or

(j) a change in hydraulic test pressure of more than 10% requires a change in design wall thickness.

1.9.3 **Design Particulars**

(a) water capacity in litres (to three significant figures)

(b) list of intended contents

(c) maximum filling pressure at 15^{o}C

(d) composite cylinder maximum service pressure

(e) composite cylinder design test pressure

(f) calculated stresses in the liner at 2/3 test pressure

(g) calculated stresses in the liner at atmospheric pressure (1.013×10^5 N/m^2)

(h) calculated stresses in the longitudinal and hoop filaments at 2/3 test pressure

1.9.4 **Manufacturing, Inspection and Test particulars**

(i) liner

(a) material, including limits of chemical analysis

(b) thickness and tolerance

(c) process and specification of manufacture

(d) heat-treatment

(e) inspection (minimum requirements)

(f) material tests (specifications and minimum requirements)

(ii) Overwrap

(a) filament material, specification and strength test requirements

(b) filament construction, strand-geometry and treatment

(c) resin system - main components, materials and specifications where applicable

d) resin system curing agent, materials and specifications where applicable

(e) resin system accelerator, materials and specifications where applicable

(f) overwrap construction

(g) curing process, approximate temperatures and minimum duration

(h) materials tests, specifications and minimum requirements

(iii) Composite cylinder

(a) autofrettage pressure and approximate duration

(b) identity and 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. MATERIALS OF CONSTRUCTION

2.1 Liner

The aluminium liner must be BS Alloy 6061 or BS Alloy 6010. The material composition of the aluminium alloy shall be within the limits shown below in Table 1.

Table 1

ELEMENT	BS Alloy 6061		BS Alloy 6010	
	MIN %	MAX %	MIN %	MAX %
Silicon	0.40	0.80	0.80	1.20
Iron		0.70		0.50
Copper	0.15	0.40	0.15	0.60
Manganese		0.15	0.20	0.80
Magnesium	0.80	1.20	0.60	1.00
Chromium	0.04	0.35		0.10
Zinc		0.25		0.25
Titanium		0.15		0.10
Lead		0.003		0.003
Bismuth		0.003		0.003
Others Each		0.05		0.05
Others Total		0.15		0.15
Aluminium	**The Remainder**			

2.1.1 A cast analysis certificate supplied by the manufacturer of the liner material shall be kept at the cylinder manufacturers premises.

2.1.2 The cast shall be identified to the satisfaction of the Verification Body.

2.2 **Overwrap**

2.2.1 The Filament material shall be glass fibre type 5 or aramid or a mixture of these materials.

2.2.2 The resin system shall be epoxy or modified epoxy with amine or anhydride curing agent.

2.2.3 The supplier of the filament material and of the resin system component materials shall provide sufficient documentation for the composite cylinder manufacture to be able to identify fully the batch of materials used in the manufacture of each cylinder.

2.2.4 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.

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

2.2.6 The filament material shall be subjected to an impregnated strand test in accordance with American Society for Testing and Material Standard ASTM 2343 or an identified equivalent specification accepted by the Verification Body.

The strength of acceptable fibre shall not be less than 3100 N/mm^2 for S-GLASS and 2760 N/mm^2 for aramid.

2.2.7 The resin system shall be subjected to a Water Boil Shear Test in accordance with American Society for Testing and Materials Standard ASTM D-2344-76, Standard Test Method for Apparent Interlaminar Shear strength of Parallel Fibre Composites by Short-Beam Method, or an identified equivalent specification accepted by the Verification Body, performed on a sample coupon which is representative of the reinforced plastic overwrap. To be acceptable the shear strength as measured shall not be less than 35 N/mm^2.

2.3 Valve fittings shall be constructed of a material compatible with the aluminium and with the gas to be conveyed.

3. MANUFACTURE, HEAT-TREATMENT AND MATERIALS TESTS

3.1 Liner

3.1.1 The liner shall be manufactured from approved processes to meet the requirement of this specification e.g. - Paragraph 14 of British Standard BS 5045 : Part 3 Wall thickness of each liner shall be greater than or equal to the minimum design thickness required by Clause 1.1 Stress Criteria. Interior folding in the liner neck area shall be prohibited but smooth gathering of the material in the neck in which there are no sharp rooted folds shall be acceptable. Liner end contours shall be concave to pressure.

3.1.2 Finished liners shall be solution heat treated at a temperature within the range 515^{o}C followed by water quenching at or below 32^{o}C and then artificially aged (precipitation treatment) at a temperature within the range 150^{o}C to 200^{o}C, to obtain the minimum mechanical properties as stated in clause 3.2.4. (Reference T6-Heat treatment process. Aluminium Association).

3.2 Materials tests on the liner

3.2.1 After heat treatment each liner shall be checked for hardness and shall achieve not less than 90 Brinell or equivalent.

3.2.2 Materials tests shall be performed on specimens cut from one fully heat treated liner in every batch. or where the number in a batch exceeds 200, from one liner in every 201 or part thereof. A batch refers to liners of the same material cast which have undergone identical heat treatment.

3.2.3 Tensile test specimens shall be made from a strip cut longitudinally from the liner. Its form and dimensions shall be in accordance with British Standard BS 18 except that for wall thicknesses less than 4.8 mm a rectangular

specimen shall be used. Gauge length of the rectangular specimen shall be 24 times the wall thickness and the specimen width shall be 6 times the wall thickness. Only the edges shall be machined, the face and the back of the test pieces shall represent the surface of the liner as manufactured.

3.2.4 The results of the tensile test shall meet the following requirements:

Tensile Strength N/mm²

Alloy and Temper	Ultimate minimum	Yield minimum	Elongation % min (1)
BS Alloy 6061-T6	262	241	12
BS Alloy 6010-T6	290	255	12

Note:

(1) 10% elongation is permitted for all thicknesses less than 4.88 mm.

Gauge length 5.65 $\sqrt{}$ AREA

3.2.5 Cold bend tests shall be made on 4 strips prepared from 2 rings cut from the same liner as that used to provide the tensile test pieces. The width of each strip shall not be less than 25 mm. In preparing the test piece, the face and back shall not be machined except that the edges may be rounded off.

3.2.6 The test pieces shall remain uncracked when bent inwards round a former of diameter not more than 6 times the actual thickness of the test strip until the interior edges at the ends of the strip are at a distance apart not greater than the diameter of the former.

3.2.7 A record of the test carried out shall be kept at the premises of the cylinder manufacturer. Suitable forms of test certificate are shown in Appendix II.

3.2.8 If any of the test results are not satisfactory, then if the Verification Body is satisfied that this was due to an error carrying out the test, a re-test may be authorised using the same liner otherwise, at the discretion of the manufacturer.

either:

(a) the test in question shall be repeated on two specimens, one from the same liner or test ring as for the first test and another one from a liner or test ring from the same batch, and if both results are satisfactory the batch may be accepted.

or

(b) the batch may be re-heat treated in accordance with 3.1.2 and retested as specified under 3.2.1 through to 3.2.6 and if the results are satisfactory the batch may be accepted.

3.2.9 Where solution heat treatment has been shown to be inadequate, liners may be subjected to re-solution treatment, once only, followed by artificial ageing.

3.2.10 Where heat treatment furnace records show artificial ageing has been inadequate, additional time at the ageing temperature shall be given.

3.2.11 If the test results, having allowed for re-testing or reheat treatment, are not satisfactory, liners in the batch shall be rendered unserviceable by one of the following methods:

(a) crushing by mechanical means;

(b) producing an irregular hole in the top dome equivalent at least to 10% of the area of the top dome, or in the case of a thin walled liner piercing it in at least three places.

(c) cutting up

Drilling a hole is not considered to be satisfactory for this purpose.

3.3 **Overwrap**

3.3.1 The composite cylinder shall be fabricated from an aluminium liner fully overwrapped with resin impregnated continuous filament windings. Winding pattern shall be "helical or inplane" and "hoop wrap" applied under controlled tension to develop the design composite thickness.

Note: liners may be stripped and re-wound provided that the overwrap has not been cured.

3.4 After winding is completed the composite shall be cured using a controlled temperature profile as specified for the system used. The maximum temperature shall be such that the mechanical properties of the liner material are not adversely affected.

3.5 The composite cylinder shall be subjected to an autofrettage pressure of not less than 116% and not more than 128% of the prescribed minimum test pressure, maintained sufficiently long for further expansion to substantially cease.

4. HYDRAULIC PRESSURE TEST

4.1 Each completed cylinder shall be subjected to a volumetric expansion test as laid down in British Standard BS 5045 Part 3 at the pressure specified with reference to Clause 1.5 above.

4.2 The cylinder is acceptable if the permanent volumetric expansion expressed as a proportion of the total expansion is not more than 5%.

5. PRESSURE CYCLE AND BURST TEST

5.1 One completed cylinder per batch of 202 (or less) shall be subjected to a pressure cycle test of 10,000 cycles from less than 0.10 test pressure to 2/3 test pressure, followed by 30 cycles up to 1.11 times test pressure.

5.2 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 5.3.

5.3 One completed cylinder per batch of 202 (or less) shall be tested hydraulically to destruction by pressurising at a uniform rate up to the failure pressure the failure pressure shall be noted.) Burst pressure shall be at least 3.33 times the filling pressure (see Clauses 1.7) and, in no case, less that the valve necessary to meet the stress criteria of Clause 1.2. Failure shall initiate in the cylinder side wall. Cylinders with a specified filling pressure not exceeding 150 bar shall remain in one piece. The cylinder subjected to the pressure cycling test of Clause 5.1 may be used for the burst test.

5.4 If the results of the pressure cycle and burst test (Clause 5.1 to 5.3) are not satisfactory, the cylinders in the batch shall be rendered unserviceable for holding gas under pressure by one of the methods under 3.2.11.

5.5 If a cylinder fails the hydraulic pressure test (Clause 4) or the pressure cycle and burst test (Clause 5.1 to 5.3) the cause shall be investigated to the satisfaction of the Verification Body. If failure is not due to an error in the manufacturing or test procedure a specimen from the overwrap material shall be prepared and tested in accordance with Clause 2.2.7. If the shear strength is less than required, a further specimen may be prepared and tested in the same manner. If this specimen also fails to pass the test the batch of material shall be rejected and any cylinders overwrapped using this batch of material shall be rendered unserviceable by one of the methods under 3.2.11.

6. DESIGN QUALIFICATION TESTS

6.1 Three completed cylinders shall be chosen at random by the Verification Body from the first production run of a new design and subjected to:

(a) a burst test in accordance with Clause 6.2;

(b) an ambient temperature cycling test, in accordance with Clause

(c) an environmental cycling test, in accordance with Clause 6.4;

6.2 One cylinder shall be tested hydraulically to destruction and meet the requirements of Clause 5.3.1.

6.3 One cylinder shall be tested hydraulically cycle tested at ambient temperature without leakage or failure.

(a) to 2/3 test pressure for 10,000 cycles, and

(b) to 1.11 times test pressure for 30 cycles.

6.4 One cylinder, free of any protective coating, shall be tested in accordance with the following sequence without deterioration, leakage or failure:

(a) conditioning for 48 hours, without pressure, at 60°C or higher and 95% or greater relative humidity;

(b) cycle testing to 2/3 test pressure for 5000 cycles under the same

conditions;

(c) stabilisation without pressure at ambient conditions;

(d) cycle testing to 2/3 test pressure for 5000 cycles at -50°C or lower;

(e) stabilisation without pressure at ambient conditions; and

(f) cycle testing to 1.1 1 times test pressure for 30 cycles at ambient temperature.

6.5 Pressure cycling tests shall be carried out using a non-corrosive fluid. The minimum (lower cyclic) pressure shall not be more than 10% of the maximum (upper cyclic) pressure and the frequency of reversals shall not exceed 15 cycles per minute.

6.6 If the cylinders subjected to pressure cycle tests are satisfactory the same cylinders shall be hydraulically tested to destruction.

6.7 Composite cylinders manufactured in a production run for which the design qualification tests do not give satisfactory results shall be rendered unserviceable for holding gas under pressure, by one of the methods listed in Clause 3.2.11. The Verification Body shall verify whether the cylinders were manufactured in accordance with the design drawings and in the absence of manufacturing errors shall notify the Health & Safety Executive of the circumstances.

7. MARKING

7.1 Each finished composite cylinder which satisfies the requirement of this specification shall be permanently and legibly marked with a label incorporated in the reinforcing wrap on the side near the outlet end of the cylinder, showing the following:

(a) the mark of this specification : **HSE-AL-FWI**;

(b) filling pressure in bar units at 15°C (permanent gases);

(c) test pressure in bar units;

(d) manufacturer's mark;

(e) mark of the Verification Body;

(f) date (month and year) of the first hydraulic pressure test;

(g) minimum water capacity in litres (liquefiable gases)

(h) serial number.

7.2 The cylinder serial number shall also be marked in a permanent manner on the top dome or by stamping on the formed neck of the liner in a low stress area agreed with the Verification Body, in a manner that will not create distortions of the cylinder profile or harmful stress concentrations.

7.3 Additional markings, e.g. re-test dates, may be contained on a label securely affixed to the cylinder side Wall and overcoated with epoxy resin.

7.4 The marking should preferably be not less than 6 mm in height, but in any case shall not be less than 3 mm.

7.5 The layout of the label and marking shall be part of the registered design.

APPENDIX I

(NOTE - Appendices do not form part of the mandatory requirements of the specification and are recommendations only).

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 3 years * from the date of the last hydraulic pressure test every composite cylinder to this specification shall be examined for defects external an internally, and before continuing in service, subjected to a hydraulic pressure test in accordance with Clause 4, by the manufacturer or a station 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 1988) and the relevant sections of BS 5430 : Part 3: 1980 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 that has no 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 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 pressure test in accordance with Clause 4.

6. Cylinders shall be rejected if they do not meet the volumetric expansion criteria or if any flaw has grown following repair and testing.

7. Cylinders shall be rejected if they do not meet the volumetric expansion criteria of if any flaw has grown following repair and testing.

8. Rejected cylinders shall be rendered unserviceable from holding gas under pressure by one of the methods listed in Clause 3.2.11.

9. In the event of doubt or dispute in connection with Clauses 4 to 7, the manufacturer, and if necessary the Verification Body, shall be consulted.

10. 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 & Safety Executive.

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

*__NB__ After the first retests performance data will be reviewed by the Health and Safety Executive. Satisfactory performance will result in the extension of the retest period to 5 years.

APPENDIX II

SPECIMEN REPORT

VERIFICATION BODIES REPORT ON:

THE MANUFACTURE OF FULL WRAPPED COMPOSITE ALUMINIUM ALLOY GAS CYLINDERS TO SPECIFICATION HSE-AL-FWI

Verification Body _____

Verification Bodies Mark _____

Certificate No _____

Place _____ Date _____

Cylinders Manufactured by _____

Manufacturers Mark _____

Manufactured for _____

Consigned to _____

Quantity _____ Overall size _____ Outside Diameter by _____ long

Serial Numbers _____ to _____ inclusive

Specification HSE-AL-FWI

Drawing No _____

Date of Hydraulic Pressure Test _____

Test Pressure _____

Water Capacity _____

Gas _____ Filling Pressure (Permanent) _____
Filling Ratio (Liquefiable) _____

Mass of Container (in Kg) Minimum _____ Maximum _____ Without valve

Minimum _____ Maximum _____ With valve

(Note: Items in brackets below refer to the Clauses of specification HSE-AL-FWI)

Each cylinder was made by overwrapping a seamless aluminium alloy liner with resin impregnated filament reinforcement.

Liner material designated as _____ was supplied by _____ and the cast analysis was within the required limits (2.1.1 Table 1).

Each liner was produced by an approved process in accordance with (3.1.1) heat treated by solution treatment followed by water quenching with artificial ageing (3.1.2) and checked for hardness (3.2.1). The results of the tensile tests (3.2.3), and cold bend tests (3.2.5) have been found satisfactory (3.2.4, 3.2.6). Overwrap was applied by winding under controlled tension filament

designated _____
supplied by _____
Impregnated with resin
designated _____
manufactured by _____

Identified by package number and cured after wrapping to the manufacturer's specification. Filaments strand strength is (2.2.6) and reinforcement shear strength (2.2.7) were verified and found satisfactory.

Calculated stress levels on the aluminium liner and the reinforcement filaments satisfy design requirements (1.1 and 1.2).

Each cylinder was subjected to an

autofrettage pressure of _____ for approximately _____

Each cylinder was subjected to a hydraulic pressure test (4.1) at the test pressure stated above and volumetric expansion was found to be satisfactory (4.2).

The results of pressure cycle test (5.1) and the burst test (5.3) on cylinders representative of the batch of which the above cylinders are a part have been satisfactory.

Each cylinder has been marked as required by the Specification (7.1, 7.2).

WE HEREBY CERTIFY that each of the above cylinders meet in full the requirements of the Specification.kj.

For and on behalf of the manufacturer.

For and on behalf of the Verification Body.

APPENDIX III

SPECIMEN TEST CERTIFICATES

1. Mechanical tests on Seamless Aluminium Alloy Liners for HSE-AL-FWI cylinders.

Batch No.	Code	Test piece dimensions	0.2% yield strength	Tensile strength	Elongation
		mm	N/mm^2	N/mm^2	%

For and on behalf of the Manufacturer _____

For and on behalf of the Verification Body _____

2. Hydraulic volumetric expansion test certificate for composite cylinders.

Customer Order No _____ Tested to a pressure of _____ and complying with HSE-AL-FWI Manufacturer's No

Container No.	Cast No.	Total Expansion	Permanent Expansion	Permanent/Total Expansion Ratio	Mass full	Mass empty	Water Capacity	Date Tested
		mL	mL	%	KG	KG	L	

Certified by _____ on behalf _____ Date _____

(for Manufacture)

Accepted by _____ Date _____

(Verification Body)