LUXFER
GAS CYLINDERS

Luxfer hoop-wrapped carbon or aramid fibre gas cylinders

LUXFER HOOP-WRAPPED CYLINDER USER MANUAL

Guide for the use, maintenance and periodic inspection in Europe of hoop-wrapped Luxfer cylinders (carbon or aramid fibre)

Table of Contents

Introduction

This is the guide for Luxfer hoop-wrapped carbon or aramid fibre gas cylinders, manufactured in compliance with the European Pressure Equipment Directive (PED) and the Transportable Pressure Equipment Directive (TPED). Luxfer high-pressure hoop-wrapped carbon or aramid fibre cylinders are designed for their intended purposes with durability in mind. Nevertheless, like all compressed gas equipment, they must be handled, maintained and inspected correctly. This user manual will help adequately trained staff to use, inspect and periodically test Luxfer hoop-wrapped cylinders safely and effectively.

Your cylinder supplier or gas company should have provided you with a document explaining the filling method and safety instructions for your hoop-wrapped cylinder. Please follow these instructions to the letter. Don't forget that you must also comply with all applicable local and national regulations for the filling, use, maintenance, and periodic testing and re-qualification of your carbon or aramid fibre hoop-wrapped cylinder.

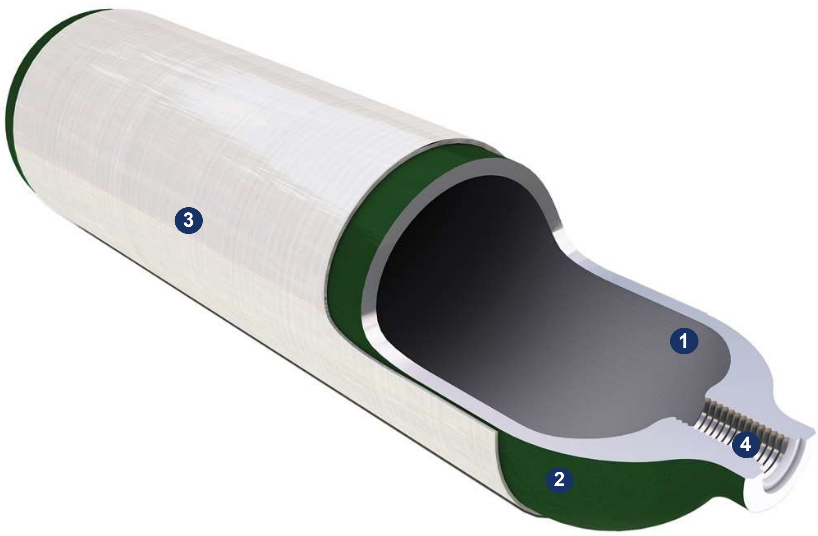
If you have any questions regarding the design, development, qualification, manufacture or testing of your cylinder, please consult ***www.luxfercylinders.com*** or contact Luxfer Customer Services on +44 115 980 3800.

1.0 Cylinder design and specifications

A carbon or aramid fibre hoop-wrapped cylinder is composed of the following basic elements:

- A lightweight, seamless liner preventing any leakage. Luxfer manufactures its liners from 7060 aluminium alloy (AA7060).

- Each liner is wound with resin-impregnated carbon or aramid fibre using PC-controlled filament winding machines.



❶ Internal surface of aluminium liner.
❷ External surface of aluminium liner
❸ High-performance resin-impregnated carbon or aramid fibre overwrap.
❹ Precision-machined thread.

1.1 Regulatory Guidelines

Luxfer hoop-wrapped carbon or aramid fibre cylinders are designed, manufactured and inspected in compliance with all applicable European standards and regulations.

European Pressure Equipment Directive (PED) – PED (**2014/68/EU**) replacing directive 97/23/EC, has been mandatory since 19 July 2016.

In the context of this manual, cylinders approved in compliance with the PED Directive are cylinders used in self-contained breathing apparatus (SCBA).

European Transportable Pressure Equipment Directive (TPED) – Directive TPED (2010/35/EU) replacing directive 99/36/EC, has been mandatory since 30 June 2011.

In the context of this manual, cylinders approved in compliance with Directive TPED are all cylinders *except for* cylinders for self-contained breathing apparatus.

2.0 Design and Performance Criteria

2.1 Design criteria

The nominal thickness of the fibre overwrap cannot be reduced to a simple formula because of the various stress-resistant layers. In addition, when these components have different strength and stiffness characteristics and are prestressed during the autofrettage process, the result is a complex distribution of stress. This phenomenon is analysed using finite element analysis techniques. All cylinders are manufactured by PC-controlled winding machines to ensure correct layering and high integrity of the overwrap.

Luxfer uses a variety of analysis techniques to produce a reliable cylinder model and to calculate maximum stresses all along the liner and fibres. Luxfer also calculates the stress distribution between the liner and the fibres at zero pressure, operating pressure, test pressure, and burst pressure. The model used to analyse the body of the cylinder takes into account the non-linear behaviour of the materials, which causes circumferential and longitudinal pressure stresses. ***Note:*** the maximum stresses at the ends of the cylinder are always examined so that they are lower than the maximum stresses in the body of the cylinder, in order to obtain positive results in burst tests.

Cylinder openings:

1. Openings are only permitted at the ends of the cylinders. The axis of the openings must match that of the cylinder.

2. The cylindrical threads must have at least six threads in order to have a shear safety factor of at least 10 at test pressure.

2.2 Qualification tests

It is not possible to use finite element modelling techniques accurately for all the different environments that a gas cylinder may be exposed to. It is necessary to carry out tests to verify that the designed cylinder does not present any hazards. These tests serve to demonstrate performances by anticipating operating stresses.

The materials of the cylinder and the composite overwrap are subjected to the following tests:

- Strength of carbon or aramid fibres.
- Inter-laminar shear strength of the composite.
- Tensile test of liner material.
- Bend test of liner material.
- Evaluation of stress corrosion susceptibility of liner material.
- Evaluation of inter-crystalline corrosion susceptibility of liner material.

Finished cylinders are subjected to the following tests:

- Repeated pressurisation at extreme temperatures from -40°C to +60°C.
- Exposure to high temperatures at test pressure (creep test).
- Fire exposure.
- Maximum cylinder resistance (hydraulic burst test).
- Repeated pressurisation.
- Thread resistance.

3.0 Cylinder manufacturing

3.1 Aluminium alloy liners

Luxfer manufactures liners that are made from 7060 aluminium alloy billet (AA7060). Each billet is impact extruded and then the open end is closed by pressure forming into a die. The liner is then quenched and tempered to develop the required mechanical properties.

The neck of the liner is then machined to form the threads and housing of the seal (if applicable).

3.2 Inspection

The raw materials are verified and identified before being processed. Liners are verified for wall thickness, straightness, concentricity and surface finish. The effectiveness of the heat treatment is verified by tensile tests on one liner sample per batch of heat treatment. The threading of each liner is also inspected.

The liners are batch-inspected in compliance with the EN ISO 7866 standard. Additional visual checks are carried out prior to winding to ensure liners are clean, free from surface defects and manufactured in compliance with the plan.

3.3 Carbon or aramid fibre overwrap

The filament winding, hydraulic pressure testing and finishing operations will be carried out at either Luxfer Riverside, USA or Luxfer Nottingham, UK.

Reinforcing the carbon or aramid fibre in an epoxy matrix provides most of the transverse strength of the hoop-wrapped cylinders. The longitudinal strength is provided by the aluminium liner. The fibres are impregnated with epoxy resin and then applied to the liner using PC-controlled filament winding machines, which ensure precision of the placement of each fibre.

The composite resin is polymerised at appropriate and controlled temperatures to ensure perfect contact between the fibre filaments and the resin system, as well as complete curing of the matrix.

Once the resin has hardened, the cylinders undergo an autofrettage process to redistribute the stresses inside the aluminium liner and the composite overwrap. Autofrettage is a pressurisation process at a specific pressure higher than the test pressure; at this stress level, the elastic limit of aluminium is exceeded, and the aluminium undergoes a plastic deformation. When the pressure returns to zero, the aluminium is under compression and the composite carbon or aramid fibre is under tension. This way, at the normal operating pressure, the stresses developed in the aluminium liner are reduced compared with those found in a single-piece aluminium cylinder.

3.4 Inspection and testing of cylinder batches

The maximum size of a batch of hoop-wrapped cylinders is 200 units, plus the number of cylinders required for destructive testing, in compliance with EN 12257 or ISO 11119-1 standards.

Each batch of hoop-wrapped cylinders is examined to ensure compliance with specifications. The following final checks are carried out according to Luxfer's quality assurance procedures:

a) Visual inspection	100% (all cylinders)
b) Check dimensions	10% or according to customer requirements
c) Check weight	100%
d) Check water capacity	100%
e) Labelling compliance	100%

For b), if a cylinder which does not comply with acceptable standards is found, all cylinders in the batch are inspected.

The following performance tests are carried out:

Hydraulic test: carried out on each cylinder after the autofrettage process, this test requires that the hydraulic pressure in the cylinder is increased gradually and regularly until the test pressure is reached. The test pressure of the cylinder is maintained for a sufficient period of time (at least 30 seconds) to ensure that there are no leaks and defects.

Hydraulic pressure rupture test: this test is carried out on one cylinder per batch. The cylinder is pressurised at a controlled rate until rupture. The pressure reached at the time of failure and the rupture mode are recorded.

Repeated pressurisation test: this test is carried out on at least one cylinder for every 5 batches. The cylinder must withstand a corresponding number of cycles, at the test pressure, equal to 2.5 times the theoretical lifespan in years (e.g. a 15-year-old cylinder will withstand 3,750 cycles at test pressure). In the case of a cylinder with an unlimited lifespan, the minimum number of cycles will be 12,000. Each cylinder must withstand the pressure cycling test without visual signs of damage, deformation or leakage.

3.5 Independent supervisory authority

Independent supervisory authority (notified body) used by Luxfer for the manufacturing of composite cylinders:

Cylinders previously manufactured in Gerzat, France
Apragaz Chaussée de Vilvorde, 156 B-1120 Bruxelles BELGIUM Notified body identification number - 0029

Cylinders manufactured in the Riverside, USA
Arrowhead Industrial Services Ltd Meadow Drove Business Centre Meadow Drove Bourne Lincolnshire PE10 0BP Notified body identification number - 1266
Cylinders manufactured in Nottingham UK
Notified Body TBA

3.6 Labelling

Each carbon or aramid fibre hoop-wrapped cylinder has a stamped or engraved marking at the cylinder shoulder. This marking must display the following information:

PED cylinders (SCBA)

- Thread reference.
- Country of manufacture.
- Manufacturer's name.
- Serial number of the cylinder.
- Gas group.
- Water capacity (L).
- Operating pressure (in bars) at 15°C.
- Test pressure (in bars).
- Date of manufacture.
- Liner material.
- Temperature range (°C).
- End of life date (if applicable).
- CE marking followed by notified body number.
- Notified body stamp.

TPED cylinders (medical applications)

- Thread reference.
- Design standard.
- Country of manufacture.
- Manufacturer's name.
- Serial number of the cylinder.
- Mass (kg).
- Water capacity (L).
- Operating pressure (in bars) at 15°C.
- Test pressure (in bars).
- Date of manufacture.
- Liner material.
- End of life date (if applicable).
- Pi marking followed by notified body number.
- Notified body stamp and country.

4.0 Use of cylinders

4.1 General indications

Follow these general guidelines to ensure correct and safe use:

Maintenance of hoop-wrapped carbon or aramid fibre cylinders: visually inspect each cylinder prior to filling, to detect any signs of damage (see Section 5). If you wish, clean the cylinder with cold tap water. You may use a mild detergent if necessary. If detergent is used, rinse the cylinder thoroughly with water. Dry all parts thoroughly before reassembling the cylinder. Do not apply heat.

Short-term storage (less than six months): close the cylinder valve correctly. Leave a pressure of 2-3 bars in the cylinder. Attach the cylinder securely to prevent it from coming loose and rolling, tipping or falling. Store at room temperature in a dry place away from all chemical products, artificial heat sources and corrosive environments.

Long-term storage: if it becomes necessary to store a cylinder for a long time, the following procedure is recommended. Empty the cylinder and remove the valve. Wash the inside and outside of the cylinder in cold tap water, rinse with distilled water and dry thoroughly, both inside and out. Carry out a visual inspection of the internal surfaces. Fit the valve and O-ring following the recommendations of the valve or system manufacturer. Once the valve is in place, a positive pressure of 2-3 bars must be maintained in the cylinder. Protect the valve from any damage. Store the cylinder in a vertical or horizontal position, at room temperature and in a dry place, away from all chemical products, sources of artificial heat and corrosive environments.

Handling: do not drag, drop or handle cylinders roughly. When transporting cylinders, ensure that the valve is protected against damage and that the cylinder is fixed securely in place. Cylinders should not be allowed to roll freely, tip or fall during transit. Secure the cylinders in position and ensure that they cannot be knocked or damaged by the rest of the load.

Paint: ***never*** use corrosive, caustic or acidic paint stripper, heat stripping techniques or solvents to remove paint from hoop-wrapped cylinder surfaces or to prepare these surfaces prior to painting. Touch up damaged paint with an air-drying paint. ***Never*** heat a cylinder to dry or harden the paint. In case of damage to the composite materials or the metal of the cylinder, do not paint over the damaged part. Have the cylinder inspected by an approved technician. It should not be necessary to completely paint a composite cylinder. In the unlikely event that full painting is required, seek Luxfer's recommendations.

4.2 Approved gases

Luxfer hoop-wrapped carbon or aramid fibre gas cylinders are manufactured for use in a variety of services and applications. Refer to ISO 11114-1 or Part 4 [Packing and Tank Provisions] of the European Agreement regarding the International Carriage of Dangerous Goods by Road (ADR) or contact Luxfer Gas Cylinders for further information on gases that can be stored safely inside Luxfer composite cylinders.

Luxfer hoop-wrapped carbon or aramid fibre gas cylinders used in self-contained breathing apparatus are approved in compliance with the Pressure Equipment Directive (PED) for use with air. The marking of the cylinder shows the name of the gas and the cylinder must only be filled with the gas indicated.

4.3 Filling the cylinders

As the composite material used in the cylinder is a good insulator, the heat generated by the filling process takes longer to dissipate than for traditional all-metal cylinders. Therefore, a cylinder filled at normal filling pressure will reach temperatures of over 49°C, especially if it is filled quickly. (***Note:*** this temperature is significantly lower than any temperature that can damage aluminium or composite material). Once the cylinder has returned to room temperature, the internal pressure will drop slightly, and the cylinder will not be fully filled. It will be necessary to complete filling.

However, it is possible to optimise filling procedures (for example, by varying the filling speed) to obtain a full load.

Slow filling: slow filling will considerably reduce the heat generated by the filling process. A maximum load speed of 30 bars/min or less is advised.

Fast filling: a Luxfer composite cylinder may be filled quickly and reused as long as it is correctly handled, well-maintained and kept in a perfect condition. The filler must, however, ensure they do not exceed the maximum operating pressure.

Compressed air: when filling composite cylinders with compressed air, always ensure that the compressor has been correctly maintained so that the air quality complies with the appropriate standards.

In the case of non-controlled use, if there is possibility of moisture penetration inside the cylinder, check the inside of the cylinder at least every six months. Do not heat. If contaminants are detected inside the cylinder, it must be cleaned and dried according to the indications provided in section 8 of this manual.

Oxygen: only use cylinders, valves and other parts specifically prepared for oxygen or oxygen-enriched gases (the term "oxygen-enriched" refers to applications for which air containing more than 23.5% oxygen is used). Only use approved lubricants for oxygen and oxygen-enriched gas applications. Non-approved lubricants, especially those containing hydrocarbons, may react with oxygen and cause a fire/accident.

The inside of the cylinder, the valve thread, the O-ring and any material that comes into contact with oxygen must be cleaned before being used for oxygen or oxygen-enriched gas applications and be free of contaminants that may react with oxygen. For further information on the use of oxygen and oxygen-enriched gas mixtures, contact Luxfer or the manufacturer of the oxygen equipment.

5.0 Periodic inspection and re-qualification

5.1 External inspection

Hoop-wrapped carbon or aramid fibre cylinders should be inspected periodically for signs of exterior damage to the overwrap. Early detection and proper restoration will keep them in operation.

Cylinders must be clean and any accessories that may interfere with the visual inspection must be removed.

The outer surface of a hoop-wrapped cylinder looks and feels different from an all-metal cylinder, so there are differences in appearance and acceptance criteria.

Clean the outer surface of the cylinder, taking care to remove any coating, tar, oil or other foreign matter residue using the appropriate methods (e.g. washing and light brushing). Shot blasting is ***not*** suitable. Do ***not*** use chemical cleaners, paint strippers, or solvents that may harm the composite material (see the illustration in section 6.9 and the warning below). Paint removal is neither necessary nor recommended prior to inspection. (If touch-up or repainting are required, see Section 8.2 *Repainting*).

Chemical exposure: composite materials can be attacked by chemical substances and, in some cases, by treated water. If a cylinder has been exposed to chemicals or aggressive fluids, check the exterior surfaces of the composite material to detect any visible signs of damage. If you know that the cylinders have been covered, splashed or soaked in one or more unknown chemicals, contact Luxfer. These substances may have damaged the composite material.

Reject hoop-wrapped cylinders when the surface of the composite is stained or if the paint or resin shows signs of etching (for example, the paint or resin has softened parts, marks, bubbles, etc.)

CAUTION: certain chemicals damage composite materials. The types of chemicals listed below damage, attack, or harm composite materials. Any composite material of a cylinder that comes into prolonged contact (e.g. soaking) with these types of chemicals and materials must be *rejected*:

***Solvents:* paint thinners, kerosene, turpentine, paint solvents, paint cleaners, epoxy solvents, resin-based solvents, biological solvents and other aggressive solvents.**

***Automotive fluids:* materials containing benzene, electrolytes/alkalis, oils containing solvents, flammable materials, gasoline and oil additives, fuels.**

***Strong bases:* materials containing moderate to high concentrations of sodium hydroxide, potassium hydroxide and/or other hydroxides.**

***Acids:* materials that are or contain acid concentrations, including hydrochloric, sulphuric, nitric and phosphoric acids.**

***Corrosive materials:* corrosive substances or those containing corrosive components, especially the aforementioned chemical substances, as well as aggressive universal cleaners, glass cleaners, metal cleaners, resin cleaners/removers, chemical unblockers, glues, rubber sealants and other chemical sealants; also atmospheres containing corrosive gases.**

Exposure to high temperatures: as a general rule, a hoop-wrapped carbon or aramid fibre cylinder that reaches a temperature of 71°C or higher should be sent to a retesting centre for evaluation before being put back in service. Cylinders that show obvious signs of prolonged exposure to fire or high temperatures should be ***rejected*** (see Section 6.6). It is important not to confuse the temperature of the environment in which the cylinder metallurgy changes and its actual temperature.

It is also important to consider not only the temperature but also the duration of exposure; **both** of these factors are critical. Brief exposure to high temperatures may not damage a cylinder. This is particularly the case for cylinders used by firefighters with self-contained breathing apparatus (SCBA). Firefighters can wear SCBA composite cylinders safely, even though they are frequently exposed to high temperatures, because a firefighter is ***never exposed to excessive heat long enough*** to affect the properties of the cylinders. Even when wearing protective equipment, a firefighter will be sufficiently disturbed by dangerous heat to leave the premises before exposure to heat can damage a cylinder. The exceptional safety demonstrated by carbon fibre composite cylinders used in firefighting for more than a decade proves the durability and reliability of these products. SCBA cylinders ***left in a fire or in a very hot environment*** for an extended period are a hazard and must be ***rejected***.

Note: certain SCBA equipment manufacturers specify a maximum temperature, meaning that an exposed cylinder should be retested or rejected if this is exceeded. SCBA equipment users should always follow the equipment manufacturer's recommendations.

Discolouration of aramid filament winding: the colour of the aramid fibre filament winding may fade over time. This is normal and discolouration will occur more quickly if cylinders are exposed to a source of ultraviolet rays, such as sunlight (see illustration). This has no effect on the integrity or performance of the cylinder and does not require reconditioning.

5.2 Removing the valve

Before an internal inspection can be carried out, the cylinder must be emptied of its pressurised gas and the valve must be removed. Depressurise the cylinder slowly, following the safety instructions. Do not depressurise a cylinder if its contents are unknown. Flammable or dangerous gases must be removed using suitable equipment.

When the cylinder is empty, remove the valve using the correct tools, including a clamping device to prevent damage to the filament winding and the cylinder valve. *Do not use a chain vice.* Consult the valve or system manufacturer's recommendations before performing this operation. See also standard EN ISO 11623.

Luxfer recommends thoroughly inspecting the valve at this stage. Contact the equipment manufacturer to enquire about the correct valve inspection procedure.

Inspect the valve and cylinder threads for signs of damage. Clean the O-ring housing, taking care not to remove metal and damage the housing.

CAUTION: if the valve is difficult to remove STOP! If the valve is damaged or does not work correctly, the inspector/operator might *think* that the cylinder is empty after having opened the valve without hearing gas escaping. All cylinders with valves that you *think* are empty should be handled *as though they were pressurised. Luxfer shall not be liable for faulty or incorrectly installed valves used with Luxfer cylinders.* If the valve does not work correctly, contact the equipment manufacturer for recommendations before proceeding.

5.3 Inspection of the inside of the cylinder

Inspecting the inside is normally only required during periodic inspection and retesting. Each cylinder must be inspected internally to comply with the requirements of this inspection guide. More frequent inspections are necessary in cases where the cylinders are loaded with respiratory air and have not been dried and cleaned according to our advice (see section 4.3) or when water has got inside the cylinder during use.

The inner surface of each cylinder should be inspected using sufficient lighting to detect any sign of damage. The inside of the cylinder must be free of dirt and other foreign matter before inspection. If the internal surfaces are not clean, they must be cleaned in order to carry out a proper inspection (see section 8.1 *Drying and cleaning*).

Recommended inspection equipment: use a dental-type magnifying mirror and a high intensity light that will sufficiently illuminate the threads and the internal diameter under the threads. Optical Plus^{TM} and similar magnifying devices, with built-in lamps, are other examples of possible inspection tools. However, do not forget that *magnifying devices may give the impression that minor, superficial defects are more serious than they actually are.* If you have any doubts about a surface defect seen through a magnifying device, contact Luxfer before rejecting a cylinder.

Reject all cylinders with isolated internal corrosion pits with an estimated depth of more than 0.75mm.

Reject all cylinders showing signs of in-line corrosion in the sidewall or generalised corrosion when the depth of one or more in-line corrosion pits exceeds 0.50mm and/or if the generalised internal corrosion is greater than 0.50mm deep.

Reject all cylinders with protuberances or cavities on the inside of the liner. These are indicators of shocks or other forms of serious damage.

Threads: inspect clean threads for cracks, fractures, and other forms of damage with a dental-type magnifying mirror and high intensity light, or an Optical Plus™ device or similar. Look for signs of corrosion on the cylinder threads and valve threads (if the valve is available).

If the thread type cannot be determined, contact Luxfer Gas Cylinders.

Remove the O-ring. Inspect the recess and the side of the cylinder for potential cracks. Follow the equipment manufacturer's recommendations for the O-ring replacement interval.

Reject all cylinders with corroded or damaged threads.

Reject all cylinders showing signs of cracks on more than one entire continuous thread. Contact Luxfer with this information. If you are not sure whether you have detected a tool stop mark or a crack, contact Luxfer before rejecting the cylinder.

Reject all cylinders with cracks in the recess, side and other signs of damage that may prevent effective and safe sealing.

Put back into operation all cylinders with acceptable recesses, sides and threads (including those with benign tool stop marks; see *Recommended Inspection Equipment*, above).

CAUTION: do *not* replace parts without following the valve or system manufacturer's instructions. Replace parts *only* with parts approved by the valve or system manufacturer.

5.4 Pressure test

Each cylinder must be pressure tested in compliance with EN ISO 11623 standard. This may be a hydraulic pressure test or a volumetric expansion test, depending on the cylinder design. The test pressure will be established from the cylinder markings.

Dry the cylinders completely after the pressure test. Do *not* use air heated above 23°C or place the cylinder in an oven to heat it. Inspect each tested cylinder for residual moisture before replacing the valve.

6.0 Cylinder damage criteria

6.1 General information

The acceptance and rejection criteria given in this Luxfer manual corresponds to the manufacturer's recommendations and do not replace the criteria imposed by local regulations (if any).

Start by checking the marking to ensure that the cylinder has not exceeded its end of life (if applicable).

Although Luxfer hoop-wrapped carbon or aramid fibre cylinders are approved without accessories, they usually have protective sleeves to protect the composite part.

Damage to the composite overwrap can take many forms. Examples of these are described in the following sections.

Luxfer recommends a classification according to three damage categories according to EN ISO 11623 standard (note that in some of the cases specified below, only levels 1 and 3 are used).

Level 1 Damage is minor damage, considered normal wear and does not affect the integrity or safety of a cylinder. This level of damage does not require reconditioning at the time of the retest. Cylinders with level 1 damage may remain in operation.

Level 2 Damage is intermediate damage and requires reconditioning to prevent further degradation. Level 2 damage may be rectified, and reconditioning must take place prior to retesting and recommissioning of the cylinder.

Level 3 Damage is severe enough for the cylinder to be ***rejected and condemned***. Level 3 damage ***cannot*** be repaired.

6.2 Abrasion

Abrasion damage is caused by wear resulting from friction.

Level 1 Damage, minor scratches and abrasions are acceptable and do not require reconditioning. Level 1 abrasion is limited to depths less than or equal to 1% of the hoop thickness.

Level 2 Damage is abrasion that can be rectified (see *Section 7: Reconditioning procedure* for more details). Level 2 abrasion is limited to depths between 1% and 3% of hoop thickness, provided that the maximum length of the damaged area is less than 10% of the outer diameter of the cylinder. All repaired cylinders must be pressure tested after reconditioning and visually inspected prior to filling.

Level 3 Damage corresponds to an abrasion depth greater than 3% of the thickness of the hoop.

Cylinders with level 3 damage must be ***rejected***.

6.3 Indentations

This type of damage consists of indentations caused by contact with blunt objects that penetrate the composite material, thus reducing its thickness at the point of contact. In a way, it can be likened to abrasion.

Level 1 Damage consists of slight indentations. Level 1 indentations are limited to depths less than or equal to 1% of the hoop thickness. It is not mandatory to repair them.

Level 2 Damage consists of deeper indentations. Level 2 indentations may cause delamination and/or fraying of fibres (see Section 6.5). This can be rectified. Level 2 indentations are limited to depths between 1 and 3% of hoop thickness, provided that the maximum length of the damaged area is less than 10% of the outer diameter of the cylinder. All refurbished cylinders (see *Section 7: Reconditioning procedure* for more details) must be pressure tested after reconditioning and visually inspected prior to refilling. Reconditioning is acceptable only if no further delamination occurs after reconditioning.

Level 3 Damage corresponds to indentations whose depth is greater than 3% of the thickness of the hoop.

Cylinders with level 3 damage must be ***rejected***.

6.4 Impact

Impact damage can occur in the form of delamination or indentations in the overwrap. All cylinders showing signs of shock should be visually inspected to detect signs of indentation to the inner surface of the metal liner. There are two recognised levels of shock damage: **level 1** and **level 3** (there is no level 2).

Level 1 Damage is slight damage resulting in a frosted appearance/area or very fine cracking at the area of impact.

It does not require reconditioning. Level 1 damage shows no sign of indentations, delamination or loose fibres, or dents. Cylinders with level 1 damage may be recommissioned.

Level 3 damage is shock damage on a large area that has a frosted appearance, delamination or loose fibres, or other clearly visible damage to the structure (e.g. cavities in the composite structure or deformation of the metal liner observed during visual inspection).

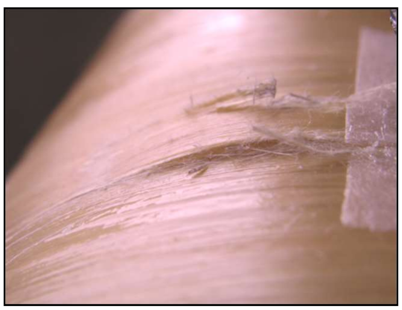
Cylinders with level 3 damage must be ***rejected***.

6.5 Delamination

Delamination is the separation of layers or strips from the composite overwrap. It may also occur in the form of areas of a whitish colour, for example in the form of a blister or air below the surface. Delamination is usually the result of shock, indentations or exposure to high temperatures.

Level 1 Damage is slight damage, for example to a small area where the carbon or aramid fibre is frosted. It does not require reconditioning (see *Shocks* above). The cylinder may be recommissioned.

Level 2 Damage is delamination limited to fraying at the ends of the fibres. Cylinders with level 2 damage may be reconditioned (see *Section 7: Reconditioning procedure* for more details) and recommissioned. All repaired cylinders must be pressure tested after reconditioning and visually inspected prior to filling.



Level 3 Delamination: delamination greater than **level 2** requires the cylinder to be ***rejected***.

6.6 Heat or fire exposure

Exposure to strong heat — a condition other than obvious damage by heat or fire — may or may not result in permanent fire damage to the cylinder. Exposure to strong heat occurs when the cylinder itself, without external protection, has been subjected to an environment with a temperature above 71°C.

A hoop-wrapped cylinder is not intended for prolonged use in an environment that would result in composite overwrap temperatures exceeding 71°C. However, temporary and short-term exposure to air temperatures above 71°C in a fire-fighting environment does not necessarily mean that the cylinder must be rejected. As demonstrated by extensive experience on the ground, a composite cylinder used in self-contained breathing apparatus (SCBA) worn by a firefighter can withstand limited exposure to high temperatures without being damaged (see also Section 5.3).

CAUTION: other parts used with the cylinder may not be suitable for use at temperatures of 71°C. Refer to the manufacturer's instructions for further information.

Exposure to temperatures above those used for polymerisation of the resin will result in its discolouration. This discolouration may vary from a very light golden or caramel colour to dark brown, almost black. Slight discolouration occurs naturally over time as a result of continuous direct exposure to sunlight and does not necessarily result from exposure to high temperatures. Discolouration can also be caused by soot or smoke from a fire-fighting environment. Normally, the degree and depth of the discolouration depends either on the temperature, or the duration of exposure. The higher the temperature, or the longer the exposure, the darker the resin will become.

Pay close attention to the condition of the accessories attached to the cylinder, including valves, labels, exposed metal and exterior protective paint. Their appearance may indicate prolonged exposure to heat or fire. If the valve is accessible, the condition of the overpressure safety device must be evaluated to determine the extent of the potential effects of the heat. The presence of molten plastic, burnt or frayed straps and discoloured parts may also indicate that the cylinder or apparatus has been exposed to fire.

Clean the cylinder and remove the smoke residue and dirt on the surface before inspecting thoroughly. Any used cylinder with fire-damaged material should be ***rejected***. Charring of the composite, paint, labels, valve materials indicates fire damage.

There are two recognised levels of heat or fire damage: **level 1** and **level 3** (there is no level 2).

This smoke-damaged cylinder has level 1 damage only.

Once it has been cleaned, it may be returned to service.

Level 1 Damage occurs when the surface of the composite (or protective sleeve if fitted to cylinder), or the paint is soiled by smoke or other contaminants but remains intact, with no sign that the resin has been burned. In this case, the cylinder may be recommissioned once cleaned. Over time, the resin may become stained due to exposure to heat and smoke. This is not unusual, and the cylinder may be recommissioned. Slight discolouration of the painted or unpainted surface can be assessed by cleaning the surface with a thin Scotch-Brite® scour pad, fine wire wool or 320-grit paper, and washing-up liquid mixed with lukewarm water. An immediate return to an off-white colour indicates that the cause of the discolouration is not very deep. This method can also be used to evaluate the condition of a painted surface that shows no sign of blistering or charring. After this evaluation, the cylinder must undergo a pressure test.

Level 3 Heat Damage

Level 3 Heat Damage (see illustration above) is damage caused by exposing the cylinder to excessive heat or flames. Cylinders that have suffered this type of damage must be ***rejected***.

Cylinders known to have been left unattended in a fire and showing evidence of heat damage must be ***rejected***.

Signs of heat damage include charring or melting of the composite or accessories, valve parts, protective layers, self-adhesive stickers or paint. They may also include blistering of a protective layer. The composite material takes on a dark brown or black appearance, which does not change once cleaned and evaluated, as above. If the valve is accessible, the condition of the overpressure safety device must be evaluated to determine the extent of the potential effects of the heat.

Cylinders known to have been subjected to direct fire action (e.g. prolonged exposure to flames) must be ***rejected***. Signs of fire damage may include evidence of combustion. Fire damage can occur either on an isolated part of the cylinder surface, or across a wider area.

6.7 Structural damage

A cylinder is rendered irreparable if it shows signs of surface swelling or depressions, distorted valve connectors, or deformation of the aluminium liner revealed by a visual inspection of the inside of the cylinder. In some cases, there may be irregularities in the carbon or aramid fibre overwrap; these are normal and should not result in the cylinder being rejected. Contact Luxfer if you are uncertain about how to distinguish these normal characteristics from signs of damage.

6.8 Chemical attack

Chemical products can dissolve, corrode, soften, attack or destroy cylinders' composite materials. They can also cause blistering, pitting or severe tarnishing of the resin; deterioration of the resin or protective paint layer, or create multiple transverse cracks with respect to the direction of the fibre. Solvents can sometimes make the cylinder sticky to the touch. Cylinders displaying signs of this type of damage must be ***rejected***.

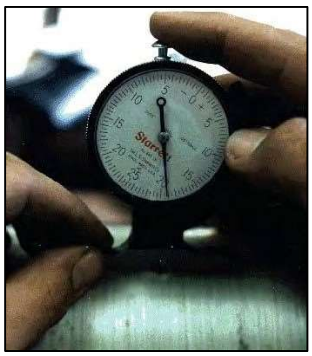
Effect of chemical attack

7.0 Rework procedure

All cylinders that have been reworked must be submitted to a hydraulic pressure test before being recommissioned. After the pressure test, the reconditioned areas must be carefully examined to detect signs of detachment or delamination of the composite material.

Any cylinder displaying such signs must be ***rejected***.

Place the cylinder on a table or worktop, with the damaged part clearly displayed, facing upwards. Check the damaged area thoroughly, in accordance with allowable defect limits.



Make sure the surface is clean and dry. Cut off all loose glass fibres. Lightly rub the damaged area with fine sandpaper or a Scotch-Brite® scour pad to prepare an acceptable surface for proper adhesion.

Mix enough quantity of two-part epoxy resin, according to the manufacturer's instructions. The epoxy resin hardens quickly; it is therefore important to apply it quickly once it has been mixed. Apply a sufficient quantity of resin to the damaged area, using the applicator to thoroughly coat and flatten loose fibres. Fill the damaged area completely with resin.

Allow the epoxy resin to harden, according to the manufacturer's recommendations. Transfer the cylinder to a protected location and do not touch it until the resin is fully hardened in compliance with the manufacturer's recommendations. Apply the desired finish to the rework. Submit the cylinder to a pressure test before returning it to service.

8.0 Final operations

8.1 Drying and cleaning

The following procedures are recommended for cleaning hoop-wrapped cylinders. Should any problem arise other than those detailed below, contact Luxfer Gas Cylinders.

CYLINDER EXTERIOR	
PROBLEM	CLEANING METHOD
Moisture and light stains	Wipe with a clean, soft cloth.
Oil and grease	Degrease with mild soap and water and dry thoroughly (dry cloth or compressed air).
Dirt and soot	Clean with mild soap and water, then dry completely (dry cloth or compressed air).

CYLINDER INTERIOR	
PROBLEM	CLEANING METHOD
White deposits or stains	Shake with nut shells, plastic balls or other non-aggressive objects. Wash the inside of the cylinder with hot water and dry thoroughly. Do *not* use air heated above 71°C or place the cylinder in an oven to heat it.
Odour	Wash with hot water and dry thoroughly. Do *not* use air heated above 71°C or place the cylinder in an oven to heat it.

8.2 Repainting

Luxfer does not recommend stripping the paint already present on the cylinders as this operation can only be performed efficiently using specialised equipment.

Never use paint stripper, heat stripping techniques or solvents to remove paint from aluminium or composite surfaces. If the cylinder is dirty, clean the exterior surface with a mild water-based detergent, rinse and dry thoroughly. Do ***not*** use heat to dry the cylinder. In case of signs of damage to the composite materials of the cylinder, an authorised technician must visually inspect it before it is painted.

If the composite materials are in a good condition, lightly sand the outside of the cylinder with 320 grit or finer paper to prepare the surface and allow the paint to adhere well.

Touch up damaged paint with an air-drying paint. ***Never*** heat a cylinder to dry or harden the paint.

The type of air-drying paint is not critical, but flame-retardant epoxy or polyurethane paint is recommended. Do ***not*** thin solvent-based paints with toluene, xylene, or other aggressive solvents. Water-based polyurethane paint has good flame-retardant properties.

Spray painting normally gives a better finish.

If the entire cylinder is to be painted, contact Luxfer for recommendations.

Take care not to paint on the top surface of the neck of the cylinder, as painting in this area may affect the tightness of the valve.

Contact Luxfer for any questions or additional information.

8.3 Fitting the valve

The choice of valves and regulators must comply with the requirements of EN ISO 13341 standard.

Before inserting the valve into the cylinder, inspect it thoroughly and, if necessary, recondition it in compliance with the valve and/or system manufacturer's recommendations. Do not install a valve that has not been inspected. Otherwise, the cylinder may give unsatisfactory operational performance.

The valve threads must be free from damage. Use an appropriate gauge to ensure that the valve complies with the correct thread specification. The valve mating surface on the valve should be smooth and in perfect condition.

Damaged or deformed valve threads may damage the cylinder threads. Damage to the sealing surface can prevent sealing and damage the top surface of the cylinder, which maintains the seal.

Parallel threads: ensure that the O-ring groove and the cylinder threads are clean and free from damage.

Install a new O-ring on the valve in accordance with the valve or system manufacturer's recommendation.

A thin layer of hydrocarbon-free, oxygen-compatible silicone grease can be applied to the bottom three or four threads to lubricate. However, ensure you do not apply grease to the underside of the valve stem. Only a small amount of grease is needed. Too much grease can cause sealing problems.

CAUTION: hydrocarbon-based lubricants should *not* be used on cylinders containing oxygen or oxygen-enriched gas!

Insert the valve into the neck of the cylinder and tighten, first by hand to make sure the threads are correctly aligned. Finish tightening the valve according to the method recommended by the equipment or system manufacturer. In the absence of data from the manufacturer, refer to the torque values specified in EN ISO 13341 standard.

Tapered thread: check that the cylinder thread is clean and free of damage.

In compliance with EN ISO 13341 guidelines, cover the valve thread with oxygen-compatible PTFE (Teflon®) tape and insert the valve into the cylinder neck. Tighten by hand, ensuring that the threads are correctly aligned and fully engaged. Finish tightening the valve applying the torque values recommended by the equipment or system manufacturer. In the absence of data from the manufacturer, refer to the torque values specified in EN ISO 13341 standard.

8.4 Destroying non-approved or expired cylinders

To destroy non-approved or expired cylinders, drill a hole of at least 13mm diameter through the overwrap and liner, thereby preventing the cylinder from containing gas.

WARNING: even when emptied, a cylinder may contain a large amount of residual gas (the safety procedure is explained in Appendix A of EN ISO 11623 standard).

9.0 Summary

9.1 Maintenance of Luxfer hoop-wrapped carbon or aramid fibre gas cylinders

ALWAYS

Always check for air leaks during each refill.

Always ensure that the thread and the inside of cylinders are dry and free from oil, dirt and other contaminants.

Always fill cylinders with the correct gas, according to the recommendations of the equipment manufacturer. *Always* follow the appropriate inspection recommendations.

Always follow the installation procedures and recommendations of the valve and/or system manufacturer.

Always maintain the accessories used with the cylinder exactly as recommended by the manufacturer.

NEVER

Never fill a leaking cylinder.

Never fill a damaged cylinder.

Never fill a cylinder if it has exceeded the required retesting date.

Never fill a hoop-wrapped cylinder that has exceeded its permissible useful life (if applicable).

Never empty a cylinder completely (unless the valve is being removed) as this can allow moisture to enter the cylinder.

Never use hydrocarbon-based lubricants with oxygen.

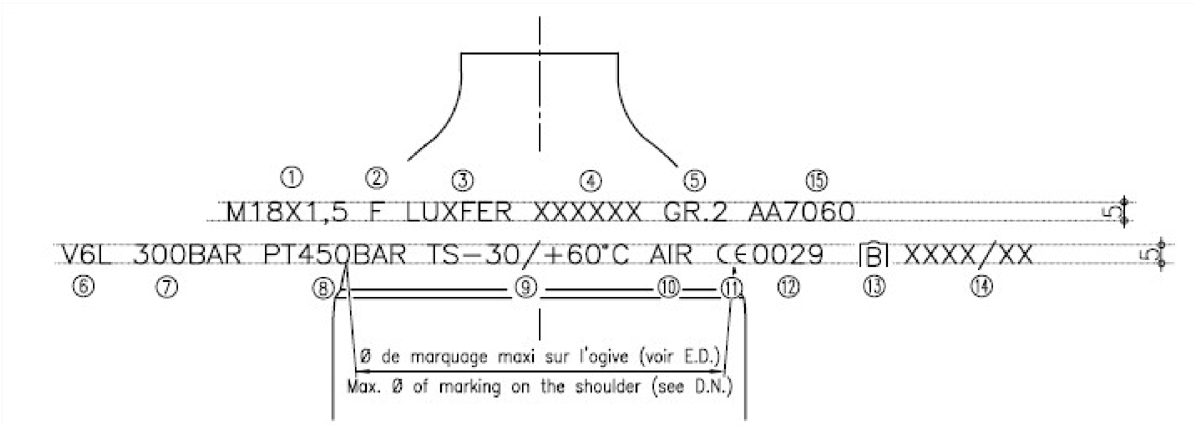
Never use components that are not compatible with oxygen or oxygen-enriched gases. *Never* overtighten a valve.

Never remove, conceal or tamper with the manufacturer's labels.

Never use a cylinder that has been exposed to an extremely corrosive atmosphere or environment without first inspecting and testing it correctly.

Never use a cylinder that has been exposed to extreme heat or fire for an extended period of time without testing it correctly first.

10.0 APPENDIX 1: Example of PED marking



1	Identification of cylinder thread.
2	Country of origin.
3	Manufacturer's identification.
4	Manufacturing serial Nr.
5	Product Group.
6	Medium water capacity.
7	Service pressure
8	Test pressure.
9	Minimal and maximal acceptable temperatures .
10	Name of the gas.
11	'CE' mark.
12	Identification Nr of the notified body.
13	Stamp of the notified body (APRAGAZ).
14	Test date (Year/Month).
15	Identification of alloy.

11.0 APPENDIX 2: Protective sleeves

Luxfer hoop-wrapped cylinders are usually equipped with protective sleeves to protect them against shocks, thereby avoiding damage to the composite. The following procedures explain how to install protective sleeves, and how to remove them safely.

11.1 Fitting the protective sleeves

1) Install the heat-shrinkable sleeve on the cylinder

2) Retract the sleeve using a suitable tunnel furnace (or heat gun)

3) Placing lengthways

Pay attention to temperature and duration of exposure.

11.2 Removing the protective sleeve

Tool recommended by Luxfer

1) Insert the tip of the adapted tool between the hoop and the sleeve

2) Make an incision in the sleeve with the blade and pull the tool towards you:

12.0 References

EN ISO 11623: Transportable gas cylinders – Periodic inspections and tests of composite gas cylinders.

NF EN ISO 13341: Gas cylinders – Fitting valves on gas cylinders.

EN 12257: Transportable gas cylinders - Seamless composite hoop-wrapped cylinders.

ISO 11119-1: Composite gas cylinders -- Specifications and test methods -- Part 1: Composite hoop-wrapped gas cylinders.

ISO 7866: Gas cylinders -- Seamless aluminium alloy gas cylinders for refilling -- Design, construction and testing.

EN ISO 7866: Gas cylinders - Seamless aluminium alloy gas cylinders for refilling -- Design, construction and testing.

ISO 11114-1: Gas cylinders -- Compatibility of cylinder and valve materials with gaseous contents - Part 1: Metallic materials.