Luxfer Carbon Composite Cylinders

# LUXFER LCX USER MANUAL

*A guide to the use, maintenance and periodic inspection of Luxfer full-wrap carbon composite cylinders in Europe*

Luxfer®
Gas Cylinders

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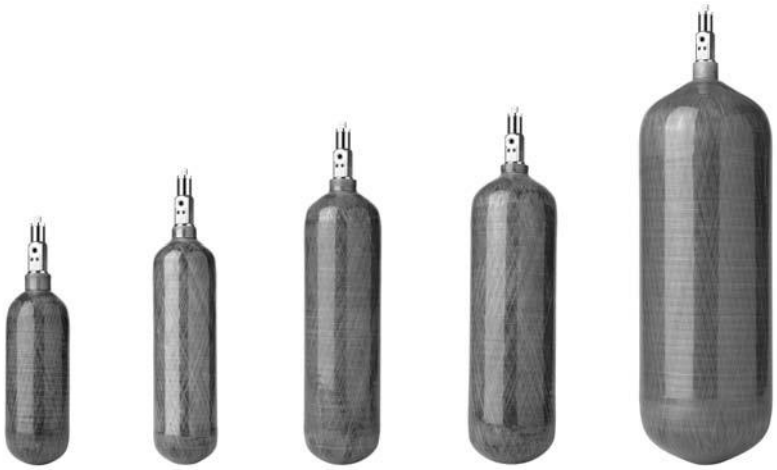
# Introduction

This guide is intended for use with Luxfer fully wrapped carbon composite cylinders manufactured to the PED (Pressure Equipment Directive) and TPED (Transportable Pressure Equipment Directive) as adopted by the European Standards Council. Luxfer high-pressure carbon composite cylinders are durably designed for the applications and purposes in which they are used; nevertheless, like all compressed gas equipment, they must be treated, maintained and inspected properly. This users' manual will assist suitably trained personnel to operate, valve, inspect and periodically test Luxfer composite cylinders safely and effectively.

Your system supplier or gas company should have provided you with instructions for the safe and proper filling of your composite cylinder. Carefully follow those instructions. Please bear in mind you must also follow all applicable local and national regulations concerning the filling, use, maintenance and periodic retesting and requalification (retest) of your composite cylinder.

If you have questions about the design, development, qualification, manufacturing or testing of your cylinder, visit Luxfer's website at ***www.luxfercylinders.com*** or call Luxfer customer service at +33-473-236400 or +44-115-9803800.



# **Luxfer:** *Setting the Standard Worldwide*

Founded in 1898, Luxfer is the world's largest manufacturer of high-pressure aluminum and composite cylinders with a diverse product offering ranging from small aluminum cylinders with water volumes of one litre, to large carbon composite gas cylinders with volumes in excess of 320 litres. Luxfer manufactures composite cylinders in the United States, Europe and China, and maintains sales offices around the world.

As the industry leader in research, development and innovation, Luxfer holds numerous global patents related to cylinder and metallurgical technology. Luxfer strives to continually improve the quality and performance of its products.

The following are some of the improvements and innovations that Luxfer has introduced for carbon composite cylinders:

**1993** – Introduction of a smooth gel-coat finish. Fully-wrapped composite cylinders were sold with a rough external surface until Luxfer introduced the gel-coat. This smooth, attractive finish, which resists dirt and damage and makes cleaning much easier, set a new standard for composite cylinder aesthetics.

**1994 –** Luxfer is granted approval for the manufacture and sale of full-wrap composite cylinders in Europe

**1995** – Luxfer was granted approval for sale of its carbon-fibre composite cylinders in the USA and Canada.

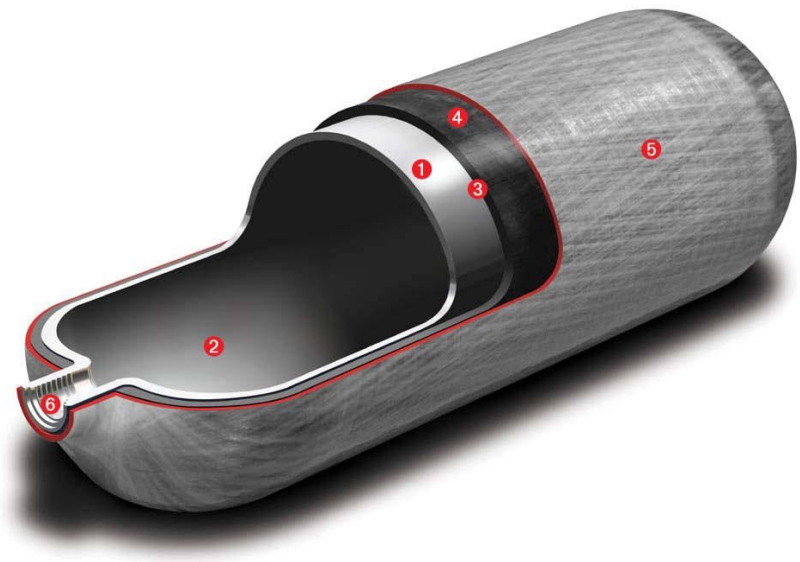
**2001** – Luxfer is granted the first approval for a five-year retest period in the USA and Canada.

**2005 –** First carbon fibre cylinders manufactured in Luxfer China, Shanghai and Luxfer France, Gerzat.

# 1. Cylinder design and specifications

A Luxfer fully wrapped, carbon composite cylinder is composed of these basic components:

- An ultra-lightweight, thin-walled, seamless aluminium liner with no leak paths or points. Luxfer manufactures its own liners from aluminium alloy 6061 (AA6061) and 7060 (AA7060). Liners receive an external coating to prevent the possibility of corrosion underneath the composite wrapping.
- Each liner is overwrapped with carbon fibre in an epoxy matrix using computer-controlled winding machines.
- A layer of glass fibre is wound onto the carbon as a sacrificial impact and abrasion layer, and a label is applied under the last layers of glass to protect it from damage.




❶ Ultra thin-walled aluminium liner

❷ Smooth, inert, corrosion-resistant internal finish

❸ Insulating layer between liner and overwrap

❹ High-performance carbon-fibre overwrap in epoxy resin matrix

❺ High-strength fibreglass-reinforced plastic (FRP) protective layer with smooth gel coat

❻ Precision-machined thread

## 1.1 Regulatory guidelines

Luxfer's full-wrap composite cylinders are designed, manufactured and inspected in accordance with all applicable European standards and regulations as required.

- **Pressure Equipment Directive (PED)** – The PED (97/23/EC) was adopted by the European Parliament and European Council in May 1997. The directive was enacted initially on 29 November 1999; however, with a period of transition that extended to 29 May 2002. As of 29 May 2002, the pressure equipment directive is obligatory throughout the EU.

  Within the context of this guide cylinders approved to the requirements of the PED are cylinders used in self-contained breathing apparatus (SCBA) applications and systems.

- **Transportable Pressure Equipment Directive (TPED)** – The TPED (99/36/EC) was enacted 1 July 2001, with a two year transition period. As of 1 July 2003, requirements of the TPED are mandatory for all new transportable (inland transport of dangerous goods by road and by rail) pressure equipment placed on the market within the European Union.

  Within the context of this guide cylinders approved to the requirements of the TPED are all cylinders of 0.5 litres water capacity or more *except* for those cylinders used in SCBA applications.

# 2. Design and performance criteria

## 2.1 Design criteria

The design thickness of the fibre overwrapping cannot be reduced to a simple formula because of varying load-bearing layers and varying orientations and thickness of composite layers. Further, when these components, with their different strength and stiffness characteristics, are pre-strained in the auto-frettage process a complex distribution of stress results. This is analysed using finite element analysis computer techniques. All cylinders are manufactured by computer-controlled fibre winding machines to ensure correct lay-up and high integrity of the overwrap.

Luxfer uses a variety of computer analysis techniques to produce a reliable model of the cylinder and to calculate the maximum stress at any point in the liner and fibres. Also calculated are load distribution between liner and fibres at zero pressure, service pressure, test pressure and burst pressure. The model used to analyse the cylinder body takes into consideration non-linear material behaviour and non-linear geometric changes, accounting both for circumferential and longitudinal pressure stresses.

***Note:*** Maximum stresses in the cylinder ends are always designed to be less than the maximum stresses in the cylinder body to pass burst tests. The maximum calculated tensile stress in any fibres (carbon or glass) must not exceed thirty percent (30%) of the fibre stress corresponding to the minimum required burst pressure.

**Cylinder openings:**

1. Openings are permitted within cylinder ends only. The centre line of the openings must coincide with the centre line of the cylinder.

2. Straight threads having at least six threads must have a calculated factor of safety in shear of at least 10 at the test pressure for the cylinder.

## 2.2 Design qualification testing

It is not possible to use finite-element modelling techniques accurately for all the different environments to which a gas cylinder might be exposed. To ensure the safe application of the cylinder design a testing program is necessary to prove performance in the anticipated service environment.

The following tests are conducted on the cylinder materials and composite overwrap:

- Strength of the carbon fibres
- Strength of the glass fibres
- Inter-laminar shear strength of the composite
- Tensile test of the liner material
- Bend test of the liner material
- Susceptibility to stress corrosion of the liner material
- Susceptibility to inter-crystalline corrosion of the liner material

The following tests are conducted on finished cylinders:

- Extreme temperature fluctuation -40ºC to 60ºC
- Exposure to elevated temperature at test pressure (creep test)
- Resistance to drop
- Resistance to flaw
- High-velocity impact resistance
- Environmental exposure at high temperatures and high humidity
- Exposure to fire
- Cylinder ultimate strength (burst test)
- Cyclic fatigue performance
- Thread resistance

# 3. Cylinder manufacture

## 3.1 Aluminium-alloy liners

Luxfer manufactures liners from 6061-alloy (AA6061) aluminium plate or 7060 (AA7060) alloy aluminium billet. Each liner is cold-drawn to thickness and hot-spun closed on the open end. The liner is then subjected to a solution heat treatment and artificial aging process to develop strength and toughness required for mechanical properties.

The liner neck is then machined for threads and port seal surfaces.

## 3.2 Inspection procedures

Raw materials are checked and identified on receipt. Liners are checked for wall thickness, straightness, out-of-roundness, concentricity and surface finish. The effectiveness of the heat treatment is verified by conducting tensile tests on a sample liner from a heat-treatment lot. The thread for every liner is verified.

Liners are inspected by lot according to EN 1975 or ISO 7866, dependent on finished cylinder design. Additional visual checks are conducted on liners prior to wrapping to ensure they are clean, free from surface defects and manufactured to the design drawing.

## 3.3 Composite overwrapping

Composite overwrapping, pressure testing and finishing operations are carried out at Luxfer Gas Cylinders facilities in Gerzat, France or Riverside, California U.S.A.

Reinforcing carbon fibre in an epoxy matrix contributes most of the strength of full-wrap carbon composite cylinders. Fibres are impregnated with epoxy resin and applied to the liner by computer-controlled filament-winding machines that ensure correct placement of each fibre. The cylinder is then overwrapped with layers of fibreglass, and an identification label is applied under the last layer of glass. The purpose of the outer layer of glass fibre is to protect the cylinder from damage. The net load-sharing capability or this layer is not considered part of the total pressure load in the cylinder at minimum required burst pressure.

Composite resin is cured using appropriate controlled-temperature profiles to ensure intimate contact between the fibre filaments and the resin system, as well as complete curing of the resin matrix.

After the resin is cured, cylinders undergo auto-frettage to redistribute the stresses within the aluminium and composite overwrap. Auto-frettage is a pressurization process at a designated pressure in excess of test pressure, and at this stress level the yield point of aluminium is exceeded—that is, the aluminium deforms plastically. When the pressure returns to zero, the aluminium is in compression and the carbon and glass fibre composite is in tension. Therefore, at normal working pressure, the developed stresses in the aluminium liner are reduced compared to those found in a standard aluminium cylinder. Luxfer applies a gel-coat finish on top of the glass-fibre layers, creating an easy-to-clean, smooth surface that is extremely resilient.

## 3.4 Cylinder lot inspection and testing

The maximum composite cylinder lot (or batch) size is 200 units, plus the number of cylinders required for destructive testing, in accordance with EN 12245 or ISO 11119-2.

Each lot of composite cylinders is examined to ensure compliance with design specifications. The following final inspections are carried out in accordance with Luxfer's Quality Assurance procedures:

| | | |
|---|---|---|
| a) | Visual inspection | 100% (all cylinders) |
| b) | Dimensional check | 10% or to customer requirements |
| c) | Weight check | 100% |
| d) | Water-capacity check | 100% |
| e) | Compliance of marking | 100% |

For b), if one unacceptable cylinder is found, then all cylinders in the lot are inspected.

The following performance tests are conducted:

**Hydraulic proof test—** Performed on each cylinder after the auto-frettage process, this test requires that the hydraulic pressure in the cylinder be increased gradually and regularly until the test pressure is reached. The cylinder test pressure shall be held for a sufficiently long period (at least 30 seconds) in order to determine there are no leaks and no failure.

**Hydraulic burst test—**This test is conducted on one cylinder per lot. The cylinder is pressurised at a controlled rate until cylinder failure. The achieved pressure at time of the failure and the rupture mode are recorded.

**Pressure cycling test—** This test is conducted on one cylinder per lot. The cylinder must withstand a corresponding number of cycles, at test pressure, equal to 2.5 times the number of years of design service life (e.g., a 15-year cylinder shall withstand 3,750 cycles at test pressure, while a 30-year

cylinder shall withstand at least 7,000 cycles at test pressure). Each test cylinder must withstand the cycling pressurization test without evidence of visually observable damage, distortion or leakage.

## 3.5 Independent inspection authorities

The independent inspection authority used by Luxfer in the manufacture of composite cylinders

| Manufactured in USA | Manufactured in France |
|---|---|
| Arrowhead Industrial Service Ltd.<br>Orion House<br>14 Barn Hill<br>Stamford<br>Lincolnshire PE9 2AE<br>UK<br><br>Notified body identification number - 1266 | Apragaz<br>Chaussée de Vilvorde, 156<br>B-1120 Bruxelles<br>BELGIUM<br><br>Notified body identification number - 0029 |

## 3.6 Marking and labeling

Each finished composite cylinder has a label applied under the fibreglass overwrap. The label contains the following information:

PED cylinders (SCBA & life support)

- Thread reference
- Design standard
- Country of manufacture
- Manufacturer name
- Cylinder serial number
- Weight
- Water capacity (L)
- Working pressure (BAR) at 15°C
- Testing pressure (BAR)
- Develope pressure at maximum temperature (BAR)
- Date of manufacture
- Liner material
- Temperature range (°C)
- End of service life date
- CE stamp followed by the number of the notified body
- Luxfer part / model number

TPED cylinder (medical & paintball)

- Thread reference
- Design standard
- Country of manufacture
- Manufacturer name
- Cylinder serial number
- Weight
- Water capacity (L)
- Working pressure (BAR) at 15°C
- Testing pressure (BAR)
- Date of manufacture
- Liner material
- End of service life date
- Pi stamp followed by the number of the notified body
- Luxfer part / model number

A Luxfer composite cylinder that still has a legible serial number can be returned to service only after all other product information is made legible. For instance, an illegible part of a composite SCBA cylinder label that still has a legible serial number can be corrected by putting required information back on the cylinder, but only Luxfer can perform this process. Contact Luxfer for further information, if needed. A sample label illustration is included as Appendix 1.

# 4. Cylinder use

## 4.1 General guidelines

Follow these general guidelines to ensure safe, proper use:

**Maintenance of carbon composite cylinders –** No regularly scheduled maintenance is required apart from periodic requalification (retest). Visually inspect each cylinder before filling for signs of damage (see Section 5.2). If desired, clean the cylinder using fresh tap water alone or water and a mild detergent, if necessary. If a detergent is used, rinse the cylinder thoroughly with clean water. Thoroughly dry all components before reassembly. Do not apply heat.

**Short-term storage (less than six months)** – Tightly close the cylinder valve. Leave a remaining pressure of 2-3 BAR (30-40 PSI) in the cylinder. Secure the cylinder and assembly to prevent the cylinder from rolling loose, tipping over or falling. Store at room temperature in a dry place, away from chemicals, artificial heat sources and corrosive environments.

**Long-term storage** – If it becomes necessary to store a cylinder for a prolonged period, the following procedure is recommended. Empty the cylinder and remove the valve. Wash the cylinder internally and externally with fresh tap water, rinse with distilled or de-ionized water and then thoroughly dry the cylinder inside and out. Visually inspect the internal surfaces. Install the valve and O-ring according to the valve or system manufacturer's recommendations. The valved cylinder should have 2-3 BAR (30-40 PSI) of positive pressure inside the cylinder valve assembly. Protect the valve from possible damage. Store the cylinder either upright or horizontally at room temperature in dry conditions away from chemicals, artificial heat sources and corrosive environments.

**Handling**—Do not drag, drop or roughly handle cylinders. When transporting cylinders, ensure the valve is protected from damage and the cylinder is well secured. Cylinders should not be allowed to roll around loose, tip or fall during transport. Secure cylinders in a protected position, and do not allow other cargo to strike or damage cylinders.

**Painting**—***Never*** use corrosive, caustic or acid paint strippers, burning techniques or solvents to remove paint from composite cylinder surfaces or to prepare those surfaces for painting. Retouch damaged paint areas with air-drying paint. ***Never*** heat a cylinder to dry or cure paint. If cylinder composite materials or metal are damaged, do not paint over the damage. Have the cylinder inspected by an authorized technician. It should not be necessary to paint an entire composite cylinder. In the unlikely event that overall painting is required, contact Luxfer for recommendations.

## 4.2 Approved gasses

Luxfer carbon composite cylinders are manufactured for and used within a number of gas services and applications. Please refer to ISO 11114-1 or Part 4 [Packing and tank provisions] of The European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR), or contact Luxfer Gas Cylinders for more information on gasses safe for storage within Luxfer composite cylinders.

Luxfer carbon composite cylinders for SCBA and life support applications are approved to the Pressure Equipment Directive (PED) for use in Europe with air and oxygen. The cylinders are marked on the cylinder label with the gas name and shall only be filled with the indicated gas.

## 4.3 Cylinder filling

The pressure of a filled cylinder must not exceed the design filling pressure indicated on the cylinder label.

Composite material used in the manufacture of the cylinder is a good insulator, and so heat generated by the filling process takes longer to dissipate than with traditional all-metal cylinders. Consequently, a cylinder charged to normal filling pressure will reach temperatures in excess of 49°C during filling, particularly if filled quickly. (***Note:*** This temperature is well below any temperature that might degrade the aluminium or the composite material.) Then, on returning to ambient temperature, the pressure inside the cylinder will drop slightly, and the cylinder will not have a full charge. Topping up will be necessary to achieve a full charge.

However, it is also possible to optimise filling procedures (e.g., by varying the speed of filling) to achieve a full charge.

**Slow filling—**Filling a cylinder slowly will significantly reduce the heat generated in the filling process. A maximum charging rate of 30 BAR/min or less is recommended.

**Fast filling—**A Luxfer composite cylinder can be fast-filled and reused if the cylinder is properly handled, well maintained and undamaged. However, the filler should take care not to exceed the maximum service pressure.

**Compressed air—**When filling composite cylinders with compressed air, always ensure the compressor has been properly maintained so that the air quality complies with the appropriate standard.

In uncontrolled conditions during which moisture may have entered the cylinder, internally inspect the cylinder at least every six months. Do not apply heat. If contaminants are found inside the cylinder, the cylinder interior must be cleaned and dried following procedures found in Section 8.1 of this manual.

**Oxygen—**Use only cylinders, valves and other components specifically cleaned for oxygen or oxygen-enriched applications. (Breathing air that contains more than 23.5 percent oxygen is generally referred to as "oxygen-enriched air.") Use only lubricants approved for oxygen and oxygen-enriched applications. Non-approved lubricants, especially those containing hydrocarbons, could react with oxygen and cause a fire.

The cylinder interior, valve threads, O-ring and any equipment coming into contact with oxygen must be cleaned for oxygen and oxygen-enriched use and be free of any contaminants that might react with oxygen. For additional information about the use of oxygen and oxygen-enriched gas mixtures, contact Luxfer or the oxygen equipment manufacturer.

# 5. Periodic inspection and requalification

## 5.1 Exterior inspection

Fibre-wrapped cylinders must be periodically inspected for exterior damage to the wrap. Prompt identification of damage and proper rework will keep cylinders in service.

The cylinder should be clean, and all attachments that might interfere with visual inspection must be removed.

Since the exterior surface of a composite cylinder does not look or feel the same as that of an all-metal cylinder, be prepared for differences in appearance and acceptance criteria.

Clean the cylinder exterior surface, removing all loose coatings, tar, oil or other foreign matter by a suitable method (e.g., washing and soft brushing). Blasting with grit or shot is ***not*** suitable. Do ***not*** use chemical cleaning agents, paint strippers or solvents that may harm the composite material (see the picture in Section 6.8 and the below statement of caution). Paint removal is neither necessary nor recommended prior to inspection. (If paint touch-up or repainting is required, see Section 8.2, *Repainting*, for guidance.)

**Chemical exposure—**Composite materials can be attacked by chemicals and, in some cases, by treated water. If a cylinder has been exposed to chemicals or aggressive fluids, check the external composite surfaces for any visible signs of damage. If cylinders are known to have been covered, splashed or left standing or soaking in an unknown chemical(s), call Luxfer for further instructions; such chemical(s) may have damaged the composite material.

***Reject*** composite cylinders if the composite surface is blotchy or if paint or resin show any signs of chemical attack (e.g., paint or resin has softened, smeared, bubbled, etc.).

**CAUTION: Some chemicals are known to cause damage to composite materials. The types of chemicals listed below are known to damage, attack or harm composite surfaces. Any cylinder composite material coming 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 solvents, resin removers, organic solvents and other aggressive solvents.**

***Vehicle fluids:* Materials that contain benzene, battery acids/alkalis, oils containing solvents, flammable materials, gasoline and oil additives and fuels.**

***Strong bases:* Materials that contain medium-to-high concentrations of sodium hydroxide, potassium and/or other hydroxides.**

***Acids:*** **Materials that are or contain any concentration of acids, including hydrochloric, sulphuric, nitric and phosphoric acids.**

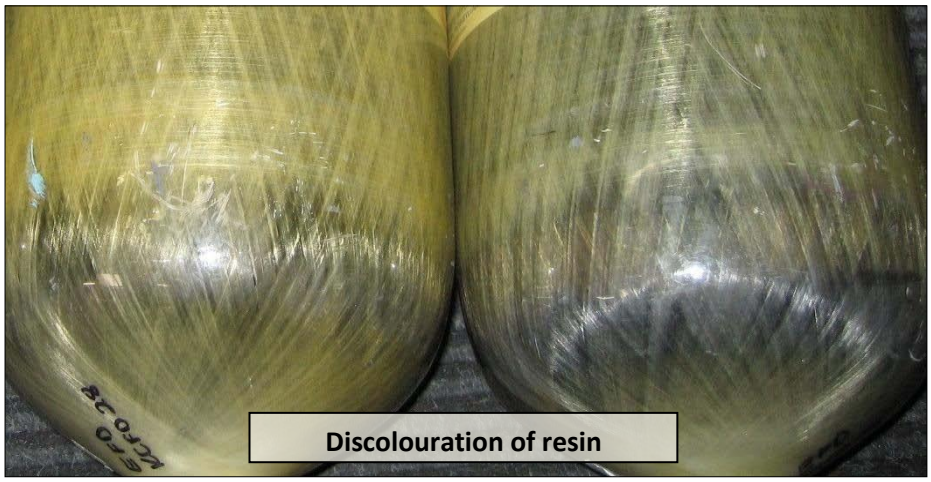
***Corrosives:*** **Corrosive materials or those containing corrosive components, including chemicals mentioned above, as well as harsh all-purpose cleaners, glass cleaners, metal cleaners, resin cleaners/removers, drain openers/cleaners, glues, rubber cement and other chemical cements; also, atmospheres containing corrosive gases.**

**High-temperature exposure**—In general, a carbon composite cylinder that reaches a temperature of 71°C or more should be sent to an authorized cylinder retest facility for evaluation before being returned to service. Cylinders that show obvious signs of prolonged exposure to fire or high temperatures must be ***rejected*** (see Section 6.6, below). It is important not to confuse environmental temperature with the actual cylinder temperature.

It is also important to take into consideration not only temperature, but also exposure time—***both*** of which are critical factors. Brief exposure to elevated temperatures may not damage a cylinder. This is particularly relevant in the case of self-contained breathing apparatus (SCBA) cylinders used by firefighters. Firefighters can wear composite SCBA cylinders with complete confidence even though they are frequently exposed to high temperatures, because a firefighter is ***never exposed long enough*** to excessive heat to affect cylinder properties. Even when wearing protective equipment, a firefighter will feel sufficient discomfort from life-threatening heat to pull back before the heat exposure could damage a cylinder. The exceptional safety record of carbon composite cylinders in fire service over more than a decade clearly proves the durability and reliability of these products. The main concern is with SCBA cylinders ***left in a fire or high-heat environment*** for a prolonged period; such cylinders must be ***rejected***.

***Note:*** Some SCBA manufacturers specify a maximum temperature that necessitates retesting or rejecting an exposed cylinder. SCBA users should always follow the original equipment manufacturer's recommendations.

**Discolouration of coating** — The cosmetic resin coating of carbon composite cylinders can discolour over time. This is a normal occurrence and the discoloration will occur more quickly if the cylinders are subjected to a UV light source, such as sunlight (see picture). This has no effect on the cylinder integrity or performance and does not require rework.




**Cracks in the cosmetic resin coating** —Superficial cracks occasionally appear in the cosmetic resin coating of carbon composite cylinders. Such minor resin cracks do not affect cylinder integrity or performance and do not require rework.

**Cracks in the vicinity of the neck wrap—**Luxfer carbon composite cylinders are often manufactured with glass fibre composite wrapping on the neck to protect exposed aluminium or to provide extra security to the threaded joint. Since this neck wrapping is not joined to the wrapping of the cylinder body, minor resin cracking sometimes occurs at the transition point due to different expansion rates of the fibres, resin and paint (see below picture). The neck-to-shoulder transition point is a low-stress area. A crack in this area is merely cosmetic and does not affect cylinder integrity or performance. No rework is necessary. If desired, such cracking can be filled according to the procedure outlined in Section 8.2. Since this is a cosmetic rework, no hydrostatic pressure test is necessary.

**Cracks in the vicinity of the base plug—**As part of the manufacturing process, a plug is inserted into the centre of the liner base, and composite material is wrapped around the plug. Sometimes superficial cracks develop in the cosmetic resin coating in the vicinity of this plug. If the area around the plug is painted, small cracks may appear in the paint, and minor porosity can also develop. These phenomena, which occur due to different expansion rates of the plug, fibres, resin and paint, do not affect cylinder integrity or performance. The base of a composite cylinder is a low-stress area, and the base plug does not contribute to cylinder strength. Superficial cracks and porosity in this area do not affect cylinder performance, and no rework is necessary. If desired, any crack or porosity can be filled and the cylinder painted, according to the rework procedure outlined in Section 8.2, *Repainting*; this is a cosmetic rework that does not necessitate a hydrostatic pressure test.

**Cracks in the label area—**Circumferential hairline cracks may appear in the cosmetic resin coating in the area of the label. Since the label is under the final layer of glass fibre, a slightly raised area results. Occasionally, superficial resin cracking occurs at the label edge. This does not affect the integrity of the cylinder, and no rework is needed.

**Variations in shape of cylinder bases –** Luxfer composite cylinders are manufactured by fibre reinforcement of a metal liner. The fibre reinforcement is built up by filament winding and as such the shape of the cylinder base can vary depending on the winding pattern or design characteristics. The picture below shows examples of the typical variation that is possible. The cylinder on the left has not been deformed by pressure but is exhibiting a more pointed shape due to the winding process.

## 5.2 Cylinder valve removal

Before an internal inspection can be performed, the cylinder must be emptied of pressurized gas and the valve must be removed. Slowly release the pressure from the valved cylinder in a safe manner. Do not de-pressurize a cylinder where the contents are not known. Flammable or hazardous gases must be vented using proper equipment.

When the cylinder is empty, remove the valve using proper tools, including a holding fixture that prevents damage to the cylinder fibre windings and valve. *Do not use a chain vise.* Consult the valve or system manufacturer's recommendations before carrying out this procedure; also see EN ISO 11623.

Luxfer recommends a thorough inspection of the valve at this time. Contact the original equipment manufacturer for the proper valve inspection procedure.

Inspect the threads of the valve and cylinder for damage. Clean the O-ring groove, being careful not to remove metal or damage the groove.

**CAUTION: If the valve is hard to remove, *STOP!* If the valve is damaged or not functioning properly, the inspector/operator may *think* the cylinder is empty after opening the valve and not hearing gas released. All valved cylinders *thought* to be empty should be handled *as if they were under pressure. Luxfer is not responsible for malfunctioning or incorrectly installed valves used with Luxfer cylinders.* If the valve is not working properly, contact the original equipment manufacturer for guidance before proceeding.**

## 5.3 Internal inspection

Internal inspection is normally required only during the periodic inspection and retest. Each cylinder must be inspected internally in accordance with requirements in this Inspection Guide. More frequent internal inspection is required in cases where cylinders are charged with breathing air that has not been dried and cleaned to the recommended levels (see Section 4.3) or when water may have been drawn into the cylinder during service.

The internal surface of each cylinder should be inspected using sufficient illumination to detect any damage. The cylinder interior should be free of dirt and other foreign material prior to inspection. If internal surfaces are not clean, it will be necessary to clean them so that a proper inspection can occur (see Section 8.1, *Drying and Cleaning*).

**Recommended inspection equipment—**Use a magnifying dental-type mirror and a high intensity light that will adequately illuminate the threads and internal diameter below the threads. Optical Plus™ and similar magnification devices with built-in lights are also helpful inspection tools—however, bear in mind that *magnification devices can make harmless cosmetic features appear worse than they really are*. If you are uncertain about a feature you see under magnification, contact Luxfer for guidance before rejecting a cylinder.

***Reject*** all cylinders with internal isolated corrosion pit(s) estimated to be more than 0.75 mm deep.

***Reject*** all cylinders with sidewall line or broad-spread corrosion when one or more interior pit(s) in the line corrosion is deeper than 0.50 mm, and/or if the interior broad-spread corrosion is deeper than 0.50 mm.

***Reject*** all cylinders that have bulges or dents on the inside of the liner. This indicates severe impact or another form of serious damage.

**Threads—**Inspect clean cylinder threads for cracks, broken threads and other forms of damage with a magnifying dental mirror and high-intensity light or with an Optical Plus™ or similar device. Check for corrosion on cylinder threads and valve thread (if the valve is available).

If you cannot determine the thread form, contact Luxfer Gas Cylinders for advice.

Remove the O-ring. Inspect the O-ring gland and cylinder face for cracking. Follow the original equipment manufacturer's recommendation about when to replace the O-ring.

***Reject*** all cylinders with corroded or damaged threads.

***Reject*** all cylinders that show evidence of cracking in more than one continuous full thread. Contact Luxfer with this information and findings. If you are unsure whether you are detecting a harmless tool-stop mark or a crack, contact Luxfer for guidance before rejecting a cylinder.

***Reject*** all cylinders with O-ring gland cracks, face cracks or other damage that may prevent an effective and safe seal.

***Return to service*** all cylinders with acceptable glands, faces and threads (including those with harmless tool-stop marks; see *Recommended inspection equipment*, above).

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

## 5.4 Pressure testing

Each cylinder must be subjected to a pressure test in accordance with EN ISO 11623. This may be a proof pressure test of volumetric expansion test, as appropriate to the design of the cylinder. The test pressure shall be established from the markings on the cylinder.

Thoroughly dry cylinders after pressure testing. Do *not* use heated air above 23°C or place the cylinder in an oven to dry. Inspect each tested cylinder for residual moisture before reinstalling the valve.

# 6. Cylinder damage criteria

## 6.1 General

The acceptance / rejection criteria given in this Luxfer manual are the manufacturer's recommendations and do *not* replace or supersede any criteria required by local regulation (if it exists).

First check the marking to ensure the cylinder is within its working life. Working life is within 15 to 30 years from the date of manufacture as indicated on the cylinder label.

Luxfer carbon composite cylinders have an outer glass fibre layer that is additional to the structural strength of the carbon wrapping. As a rule, any damage to the glass layer is either acceptable or can be reworked. However, any damage that exposes the structural carbon fibre layers is sufficient to cause rejection of the cylinder.

Damage to composite overwrapping can take a number of forms, examples of which are described in the following sections.

Luxfer recommends the use of three categories of damage in accordance with EN ISO 11623 (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-tear and that has no adverse effects on the integrity or safety of a cylinder. This level of damage does not require any rework to be performed at the time of retest. Cylinders with Level 1 damage can continue in service.

**Level 2 damage** is intermediate damage and requires rework to prevent further degradation. Level 2 damage can be reworked and all rework must be performed prior to retest and return of the cylinder to service.

**Level 3 damage** is sufficiently severe that the cylinder must be ***rejected and condemned***. Level 3 damage ***cannot*** be reworked.

## 6.2 Abrasion damage

Abrasion damage is caused by the wearing, grinding or rubbing away of material by friction.

**Level 1 damage,** which consists of minor scuffs and abrasions to the outer gel coating is acceptable and does not require rework unless the area is large enough to cause unravelling of glass fibres. Level 1 abrasion damage is limited to depths of less than or equal five percent (≤ 5%) of the composite overwrap thickness.

**Level 2 damage** is abrasion damage that can be reworked (see *Section 7: Rework procedure* for details). This is where the outer glass fibre layer has been abraded, but the damage does not penetrate completely through the glass fibre thereby exposing the underlying layer of carbon fibre. Level 2 abrasion damage is limited to depths less than or equal to 15 percent (≤ 15%) of the composite overwrap thickness, provided the maximum length of the damaged area is less than 50 percent (50%) of the outside diameter of the cylinder. All repaired cylinders must undergo a pressure test after the rework and be visually inspected before filling.

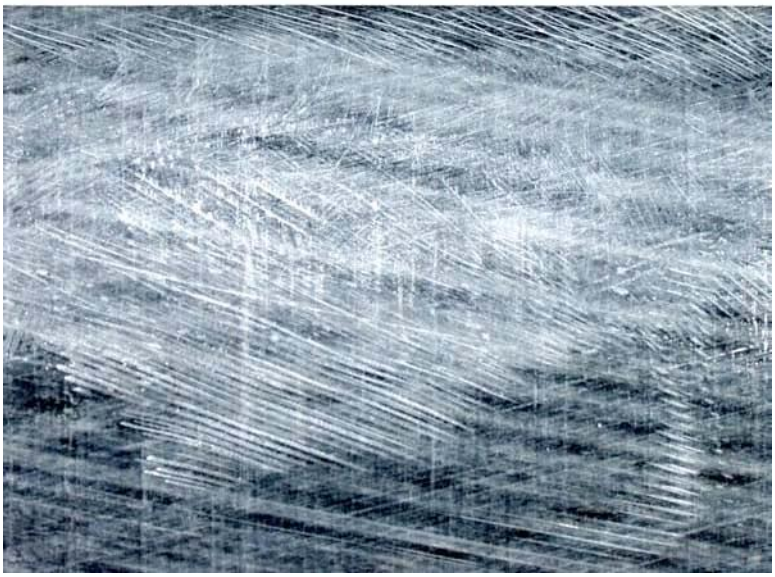
**Level 3 damage** is sufficiently severe that abrasion has passed through the outer glass fibre layer and into the underlying carbon fibre layers. ***Any exposure of the carbon fibre qualifies as Level 3 damage***.

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

***Reject*** cylinders where the carbon fibre has been exposed.

LEVEL 1
ABRASION

LEVEL 2
ABRASION




## 6.3 Cuts

This type of damage consists of cuts caused by contact with sharp objects that penetrate into the composite material, effectively reducing its thickness at the point of contact. This damage is similar in some ways to abrasion damage.

**Level 1 damage** consists of cuts to the outer gel coating or light cuts in the outer glass fibre layer. The outer glass fibre layer can be exposed, but cannot exhibit any type of damage. Level 1 cut damage is limited to depths of less than or equal five percent (≤ 5%) of the composite overwrap thickness.

**Level 2 damage** is heavier cuts in the glass fibre layer that have not extended into the underlying carbon fibre layers. Level 2 cuts can cause delamination and/or unraveling of the glass fibres (see Section 6.5) and can be reworked. Level 2 cut damage is limited to depths less than or equal to 15 percent (≤ 15%) of the composite overwrap thickness, provided the maximum length of the damaged area is less than 50 percent (50%) of the outside diameter of the cylinder. All reworked cylinders (see *Section 7: Rework procedure* for details) must undergo a pressure test after the rework and be visually inspected before filling The rework is acceptable only if further delamination does not occur after the post-rework retest.

**Level 3 damage** is cuts through the glass fibre layer that lead to the exposure of the underlying carbon fibre layer or metal liner. ***Any exposure of the carbon fibre qualifies as Level 3 damage***.

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

***Reject*** cylinders where the carbon fibre has been exposed.



## 6.4 Impact damage

Impact damage may appear as cracks in the resin, as delamination, or as cuts in the overwrap. All cylinders that show evidence of impact damage must be visually inspected for evidence of indentation of the internal surface of the metal liner. Two levels of impact damage are recognized: **Level 1** and **Level 3** (there is no Level 2).

**Level 1 damage** is light damage, such as a small area where the fibreglass is frosted or hairline cracking has occurred, and does not require rework. Level 1 damage will show no indication of cutting, delamination or peeling of fibres, or indentation. A cylinder with Level 1 damage can be returned to service.

**Level 3 damage** is impact damage causing a large area of frosting, delamination or peeling of fibres or other readily noticeable structural damage (e.g., flat indentation of the composite structure, or an indentation in the metal liner noted during internal visual inspection).

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

***Reject*** cylinders where the carbon fibre has been exposed


LEVEL 1
IMPACT

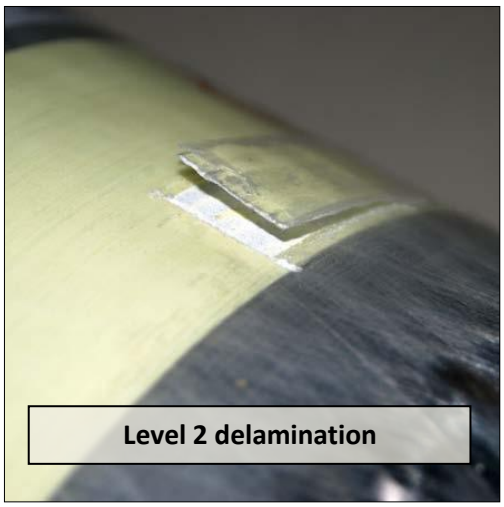

LEVEL 3
IMPACT

## 6.5 Delamination

Delamination is the separation of composite overwrap layers or strands. It may also appear as a whitish patch, such as a blister or an air space beneath the surface. Delamination is typically the result of an impact, cut or exposure to temperatures of more than 93°C.

**Level 1 damage** is light damage, such as a small area where the fibreglass is frosted, does not require rework (see *Level 1 impact* above). The cylinder may be returned to service.

**Level 2 damage** is delamination restricted to the loose fibre ends from the termination of the wrapping process. Cylinders with Level 2 damage may be reworked (see *Section 7: Rework procedure* for details) and returned to service. All reworked cylinders must undergo a pressure test after the rework and be visually inspected before filling




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

## 6.6 Heat or fire damage

Elevated heat exposure—a different condition than obvious heat or fire damage—may or may not result in permanent heat damage to a cylinder. Elevated heat exposure occurs when the cylinder itself, absent any outer protection, has been subjected to a temperature environment in excess of 71°C.

A composite cylinder is not intended for *prolonged* use in any environment that would result in composite overwrap temperatures in excess of 71°C. However, *temporary* short-term exposure to air temperatures in excess of 71°C in a firefighting environment is not cause for cylinder condemnation. As extensive field experience has shown, a composite cylinder used within a self contained breathing

apparatus (SCBA) carried by a firefighter can withstand limited exposure to elevated temperatures without damage (also see Section 5.3).

**CAUTION: Other components used with the cylinder may not be suitable for use at temperatures of 71°C. Please refer to the OEM's guidelines for further information.**

Developed composite material temperatures in excess of the original cure temperature of the composite will cause discoloration of the resin. This discoloration can range from a very light golden or caramel colour to a deep, brownish-black appearance. Light discoloration will occur naturally over time with continued direct exposure to sunlight and may not necessarily be a result of elevated temperature exposure. The discoloration may also be caused by soot or smoke from a firefighting environment. Normally, the degree and depth of discoloration is dependent on either the temperature or duration of exposure. The higher the temperature, or the longer the duration of exposure, the darker the resin will become.

Pay close attention to the condition of any attachments such as valves, decals, stickers, stencils, exposed metal (e.g., aluminium liner ends or necks) and the outer protective paint; these can indicate prolonged exposure to heat or fire. If the valve is available, the condition of the pressure relief device (PRD) should be evaluated to assess the extent of any heat effects. Fire damage to cylinders or equipment is also shown by melted plastics, burned or frayed straps and discoloured components.

Clean the cylinder and remove smoke residue and dirt from the surface before conducting a thorough inspection. Any cylinder used in equipment that has experienced fire damage should be ***rejected***. Fire damage is shown by charring or burning of the composite, paint, labels, valve materials, melted resin, absence of some or all of the resin and/or by paint damage (e.g., bubbling or melting).

Two levels of heat or fire damage are recognized: **Level 1** and **Level 3** (there is no Level 2).

**Level 1 damage** occurs when the surface of the clear gel coat, paint or composite is soiled from smoke or other contaminants but is intact underneath with no evidence that the resin has been burned. In this case, a cylinder can be returned to service after cleaning. Over time, resin can become tinted due to exposure to heat and smoke. This is not unusual, and the cylinder can be returned to service. Light discoloration of the resin gel-coat or painted surface may be evaluated by cleaning the surface with a fine-grit Scotch-Brite® scrubbing pad, fine steel wool or 320-grit sandpaper, as well as liquid dishwashing detergent mixed with warm water. An immediate colour change back to an off-white colour indicates that the cause of the discoloration has no significant depth. This method may also be used to evaluate the condition of a painted surface that shows no evidence of blistering or charring. After this evaluation, the cylinder must pass a pressure test.


**Level 3 damage** (see above picture) is damage caused by cylinder exposure to excessive heat and/or flame; cylinders exhibiting this level of damage must be ***rejected***.

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

Evidence of heat damage includes charring or melting of the composite or any attachments, valve components, protective layers, stickers or paint. Evidence can also include blistering of a protective layer. The composite would appear dark brown or black in colour and would remain unchanged when cleaned and evaluated, as noted above. The original manufacturer's label may be totally illegible due to the darkness of the resin. If the valve is available, the condition of the pressure relief device (PRD) should be evaluated to assess the extent of any temperature exposure.

Cylinders known to have been subjected to the direct action of fire (i.e., prolonged impingement by flame) must be ***rejected***. Evidence of fire damage might include signs of actual burning. Fire damage could occur either in an isolated area of the cylinder surface or over a wider area.

## 6.7 Structural damage

A cylinder is rendered unserviceable if there is any evidence of surface bulges or depressions, distorted valve connections or deformation of the aluminium liner revealed by visual examination of the cylinder interior. In some cases, there may be irregularities in the fibreglass overwrap or gel coat finish; these are normal and are not cause for rejection. Contact Luxfer if you are uncertain about how to distinguish such normal conditions from actual damage.

## 6.8 Chemical attack

Chemicals can dissolve, corrode, soften, remove or ruin cylinder composite materials. They can also cause bubbling, pitting or extreme dulling of the resin; cause deterioration of the resin or protective paint layer, or create multiple fractures transverse to the direction of the fibre. Sometimes solvents can cause the cylinder to become sticky to the touch. Cylinders with evidence of such damage must be ***rejected***.

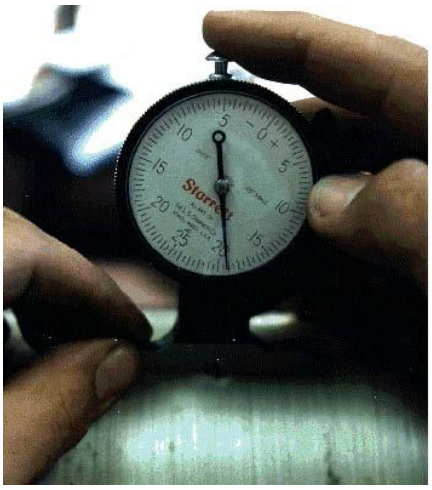
Carbon fibres are far less susceptible to chemical attack than glass fibres—but if a carbon composite cylinder has been clearly damaged by chemicals, it must be ***rejected***.


# 7. Rework procedure

All cylinders that have been reworked must be subjected to a pressure test before being returned to service. After pressure test, the rework sites must be carefully examined for any lifting, peeling or delamination of the composite material.

Any cylinder showing signs of lifting, peeling or delamination must be ***rejected***.

Place the cylinder on a table or bench with the damaged area uppermost and easy to reach. Check the damage site carefully in accordance with allowable defect limits.



Ensure the surface is clean and dry. Cut away any loose glass fibres. Slightly roughen the damaged area with either fine sandpaper or a Scotch-Brite® scrubbing pad to prepare an acceptable surface for proper resin adhesion.


Mix a sufficient amount of two-part epoxy resin according to the resin manufacturer's instructions. Epoxy resin sets quickly, so it is important to apply it without delay once it has been mixed. Apply a sufficient amount of resin to the damaged area, using the applicator to thoroughly coat and burnish down any loose fibres. Completely fill the damaged area with resin.

Where additional protection is required, apply a slightly oversized piece of fibreglass surface veil over the damaged area. Apply a thin layer of resin over the veil, making sure that the veil and damaged area are completely covered.

Where a superior surface finish is required, use shrink tape. Affix a piece of unidirectional shrink tape, approximately 150mm longer than the damaged area, with outer surface of tape facing downwards, over the damage with ordinary adhesive tape. Apply heat to the tape with a hot air dryer to cause shrinkage. Peel off the tape after the epoxy resin has fully cured.

Allow the epoxy resin to set per the timeframe detailed within the resin manufacturer's instructions. Move the cylinder to a protected location and leave it undisturbed until the resin is fully cured in accordance to the resin manufacturer's guidelines. Apply a desired finish to the rework. Pressure test the cylinder before returning it to service.

# 8. Final operations

## 8.1 Drying and cleaning

The following procedures are recommended for the cleaning of composite cylinders. For any problems other than those detailed below, please contact Luxfer Gas Cylinders for assistance.

| CYLINDER EXTERIOR | |
|---|---|
| PROBLEM | CLEANING METHOD |
| **Moisture and light soiling** | Wipe with a clean, soft cloth |
| **Oil and grease** | Degrease with mild soap and water, followed by a thorough drying (dry cloth wipe or forced air) |
| **Dirt and soot** | Clean with mild soap and water, followed by a thorough drying (wipe with dry cloth or forced air) |

| CYLINDER INTERIOR | |
|---|---|
| PROBLEM | CLEANING METHOD |
| **White deposits or staining** | Tumble with walnut shells, plastic chips or other non-aggressive media. Wash cylinder interior with hot water and thoroughly dry. Do not use heated air above 71°C or place the cylinder in an oven to dry. |
| **Odour** | Wash with hot water and thoroughly dry. Do not use heated air above 71°C or place the cylinder in an oven to dry. |

## 8.2 Repainting

Luxfer does not recommend the removal of the existing paint from cylinders, since this can only be carried out effectively by using specialized equipment.

***Never*** use paint strippers, burning techniques or solvents to remove paints from aluminium or composite surfaces. If the cylinder is dirty, clean the exterior surface with a mild water-based detergent, rinse and dry the cylinder thoroughly. Do ***not*** use heat to dry the cylinder. If any damage to the cylinder composite materials is evident, have the cylinder visually inspected by an authorized technician before painting.

If the composite materials are undamaged, lightly rub down the cylinder exterior with 320-grit or finer sandpaper to prepare the surface for good paint adhesion. Retouch damaged paint areas with air-drying paint. ***Never*** heat the cylinder to dry or cure paint.

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

Spray painting normally gives a better finish.

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

Do *not* paint over the cylinder label. If painting near the label, mask off the label to protect it and ensure future legibility (a regulatory requirement).

Take care not to spray paint onto the top face of the cylinder neck since paint in this area can impair proper valve sealing.

Contact Luxfer if you have questions or require additional information.

## 8.3 Valve insertion

Selection of valves and pressure-relief devices (PRD) must conform to the requirements of EN ISO 13341.

Before inserting the valve into the cylinder, carefully inspect it and, if necessary, rework it in accordance with the recommendations of the valve manufacturer and / or system manufacturer. Do not install any valve that has not passed an inspection. Failure to follow these guidelines can lead to unsatisfactory in-service performance.

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

Damaged or distorted valve threads can damage cylinder threads. Damage to the mating surface can prevent sealing and damage the top sealing face of the cylinder.

**Parallel threads –** Check to make sure the O-ring groove and threads of the cylinder are clean and free from damage.

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

A thin smear of silicone, hydrocarbon-free, oxygen-compatible grease may be applied to the bottom three or four threads to provide lubrication—but take care *not* to apply grease to the bottom face of

the valve stem. Only a small amount of grease is necessary. Too much grease can cause sealing problems.

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

Insert the valve into the cylinder neck and tighten first by hand to make sure the threads are properly aligned. Then finish tightening the valve in accordance with the OEM or system manufacturer's recommendations. If no manufacturer's data are available, please refer to torque values specified in EN ISO 13341.

**Tapered threads –** Check to ensure the cylinder's threads are clean and free of damage.

In accordance to the guidelines of EN ISO 13341 cover the valve threads with oxygen-compatible PTFE tape and insert valve into the cylinder neck and hand tighten ensuring proper alignment and full engagement of the threads. Further tighten the valve to torque values in accordance to the OEM or system manufacturer's recommendations. If no manufacturer's data are available, please refer to torque values specified in EN ISO 13341

## 8.4 Destruction of condemned or expired cylinders

To destroy condemned or expired cylinders, drill a minimum 13mm (0.5 inch) hole all the way through the cylinder wrapping and liner making the cylinder unable to hold gas.

**WARNING:** Even if completely vented, a cylinder can contain a significant amount of residual gas (for safety procedure see EN ISO 11623, annex A).

# Summary

## Care and maintenance of Luxfer carbon composite cylinders

### ALWAYS:

*Always* be alert for air leaks with each fill.

*Always* keep the threads and cylinder interior dry and free from oil, dirt and other contaminants.

*Always* fill cylinders with proper gas recommended by the original equipment manufacturer.

*Always* follow appropriate inspection recommendations.

*Always* follow the valve and / or system manufacturer's installation procedures and recommendations.

*Always* maintain accessory equipment used with your cylinder in strict accordance with the manufacturer's recommendations.

### NEVER:

*Never* fill a cylinder if it leaks.

*Never* fill a damaged cylinder.

*Never* fill a cylinder if it is past its required retest date.

*Never* fill a composite cylinder past its allowable life.

*Never* completely discharge a cylinder (except when you are planning to remove the valve) since it can lead to moisture entering into the cylinder.

*Never* use hydrocarbon-based lubricants with oxygen.

*Never* use non-oxygen-compatible components with oxygen or oxygen-enriched gases.

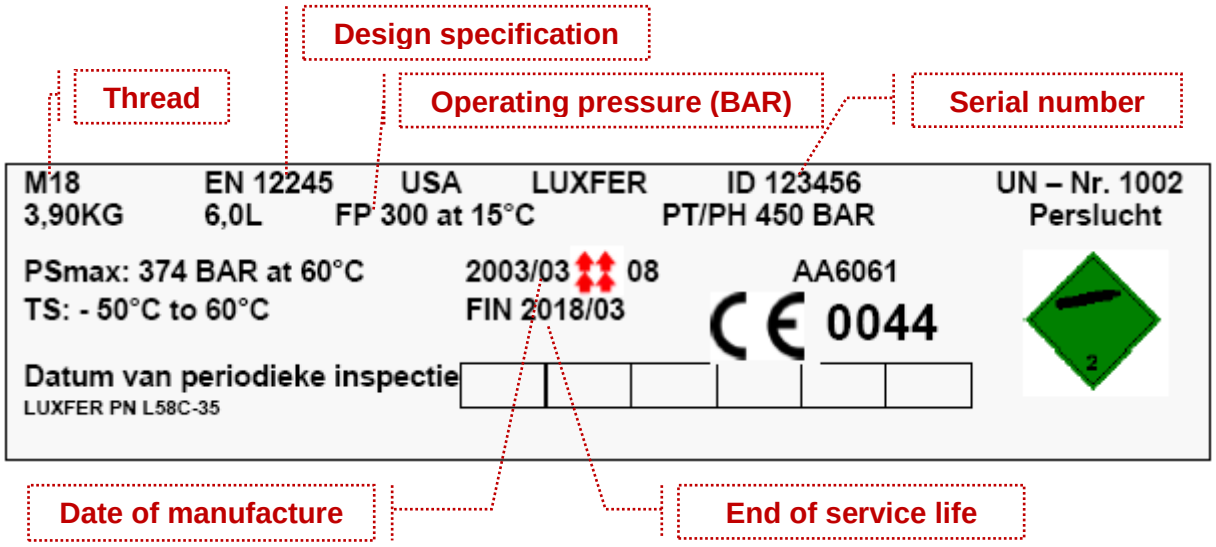
*Never* over-torque a valve.

*Never* remove, obscure or alter the manufacturer's labels.

*Never* use a cylinder that has been exposed to an extremely corrosive atmosphere or environment without having it properly inspected and tested.

*Never* use a cylinder that has been exposed to extreme heat or fire for a prolonged period without having it properly tested.

# APPENDIX 1: Sample label



# APPENDIX 2: LCX protective caps and boots

Luxfer LCX cylinders used in SCBA applications may be fitted with protective high-impact polymer caps and boots. These caps are bonded to the cylinder with a semi-permanent adhesive. The following procedures detail how to install such caps and boots, and safely remove them that the underlying composite surface may be inspected during re-qualification.

## Cap and boot installation

Luxfer recommends using Loctite® adhesive for bonding caps and boots to Luxfer LCX composite cylinders. This adhesive is commercially available or can be purchased from Luxfer, please contact Luxfer customer service for more information.

Measuring approximately 20-30mm from the edge, apply a small bead of adhesive along the inside surface of the cap / boot [*see Photo 1 below*].

Immediately after applying the adhesive, place the cap / boot firmly in place.

**Do not use heat to cure the adhesive,** as this can have an adverse effect on the cylinder's performance.

Protective caps and boots are typically re-usable. New cap and boot sets can be purchased from Luxfer, please contact Luxfer customer service for more information.

**Photo 1 – application of adhesive**

## Cap and boot removal

***Tools required:***

- Hacksaw blade or similar thin metal strip
- Adhesive kit

***Removal procedure:***

Carefully slip the hacksaw blade between the cap and cylinder [*see Photo 2 below*] to a depth of 40-50mm. Continue to insert the blade in this manner every 20mm around the circumference of the cylinder.


**Photo 2 – insert blade ~25mm beyond cap's edge**

Once the blade has been passed between the cylinder and cap around the circumference of the cylinder, the cap can be removed by lifting the cap by its edge while working around the cylinder.

Perform the same procedure to remove the boot from the base end of the cylinder.

Any remaining adhesive on the cylinder or cap / boot may be removed by rubbing the surface with a moist cloth. If necessary, isopropyl alcohol can be used to clean the cylinder's surface of excess adhesive.

**Cylinder dome after removal of cap**

# References

EN ISO 11623: Transportable gas cylinders – Periodic inspection and testing of composite cylinders.

EN ISO 13341: Transportable cylinders – Fitting of valve to gas cylinder

EN 12245: Transportable gas cylinders – Fully wrapped composite cylinders

ISO 11119-2: Gas cylinders of composite construction – Specification and test methods – Part 2: Fully-wrapped fibre reinforced composite cylinders with load-sharing metal liners.