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Gas cylinders — Guidance for design of composite cylinders

Part 4: Cyclic fatigue of fibres and liners

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National foreword

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 58, *Gas cylinders*, Subcommittee SC 3, *Cylinder design*.

A list of all parts in the ISO 13086 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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Gas cylinders — Guidance for design of composite cylinders —

Part 4: Cyclic fatigue of fibres and liners

1 Scope

This document addresses the topic of cyclic fatigue of structural reinforcing fibres as used in composite cylinders, and cyclic fatigue of structural and non-structural liners in these cylinders. This document provides a basic level of understanding of these topics.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

No terms and definitions are listed in this document.

NOTE Terms and definitions related to gas cylinders can be found in ISO 10286.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at https://www.iso.org/obp

4 Background

Composite cylinders began service in the 1950s, initially as rocket motor cases with glass fibre reinforcement. This soon led to glass fibre pressure vessels with rubber liners, and then to glass fibre pressure vessels with metal liners. Metal liners were typically either aluminium alloy or steel. Eventually, new structural fibres, such as aramid and carbon, came into use for reinforcing pressure vessels. Today, typical reinforcements for composite gas cylinders are glass and carbon, either individually or together as a hybrid. Typical liner materials are steel, aluminium alloy or polymers, for example, high-density polyethylene (HDPE) or polyamide (PA); other materials may be acceptable.

Each of these materials is subject to cyclic fatigue based on the type of service and the construction of the cylinder. Cylinders used in transport service generally see full range cycles, with a limited number of cycles per year. Cylinders used as fuel containers would typically see up to three pressure cycles per day for fleet vehicles, and less for private vehicles. Cylinders used in stationary applications such as refuelling cascades could see a very large number of partial cycles in a year. Some cylinders could see a combination of these conditions. Stationary cylinders used for fuel cells or emergency breathing applications could see a very limited number of cycles. Design working pressures for high pressure cylinders are typically in the range of 20 bar to 1 100 bar. Cylinders for liquified gases such as propane may operate at pressures up to 20 bar, and normally see fewer pressure cycles.

The different reinforcing fibres have different fatigue lives for a given stress or strain range. Liner materials will also have different fatigue lives for a given stress or strain range. The load-sharing characteristics of a liner material with a given reinforcement will affect their fatigue lives. An autofrettage cycle is used with metal lined cylinders to improve fatigue life. The low modulus of

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elasticity of polymer liner materials often results in the liner being in compression when the cylinder is pressurized, so their fatigue life could be very high. Welds in a liner, whether it is metal or polymer, can affect the fatigue life due to the different mechanical properties in a weld and in heat affected zones.

Surface quality and conditions such as roughness will affect cyclic fatigue, particularly crack initiation. Autofrettage generally blunts cracks, and adds surface compression, which will improve fatigue life.

Evaluation and understanding of cyclic fatigue will lead to improved designs and reduce the risk of cyclic fatigue failures without the need to overdesign the cylinders or conduct extensive qualification testing on each new design.

5 Cyclic fatigue evaluation

Cyclic fatigue of composite cylinders can be addressed with an understanding of:

— service conditions and requirements;

— test conditions and specimens;

— fibre materials and their fatigue properties;

— liner materials and their fatigue properties;

— resin materials and their fatigue properties;

— composite/liner load sharing;

— autofrettage;

— analysis methods;

— leak before burst (LBB);

— damage tolerance;

— aging and environment;

— counting and combining different cycles;

— qualification testing.

6 Elements of cyclic fatigue

6.1 Service conditions and requirements

6.1.1 Temperature and moisture

Service conditions depend largely on location and usage of the cylinder. If the cylinders are located and used outdoors, they must be able to withstand ambient conditions. Common conditions include temperature ranges from −40 °C to +85 °C (−40 °F to +185 °F), which include higher temperature exposure due to solar input and storage in confined spaces. This may include use in a vehicle or shipment in a rail car where direct sunlight will raise temperatures within the storage compartment. Surface absorptivity and emissivity of the cylinder can affect solar input to the cylinder and its equilibrium temperature. It is less common to require operation in temperatures to -55 °C (−67 °F), and in some cases to even lower temperatures.

Moisture levels in outdoor locations would range from very high to very low depending on ambient conditions. Some cylinders are actually located in a water bath. Moisture itself generally does not affect fatigue of structural materials used in cylinders, but can cause corrosion, which could affect fatigue life. Moisture can also be absorbed into polymer liners, and resulting property changes should be

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understood by the cylinder designer. Moisture can also bring in chemicals that could affect material strength and fatigue properties, particularly those glass fibres that are not corrosion resistant.

Some cylinders are maintained in a controlled environment, such that temperature and moisture are monitored and controlled. However, conditions must be guaranteed if a controlled environment is required to meet fatigue requirements. Otherwise, it is best to assume the cylinders will be exposed to worst-case conditions.

Temperature and moisture changes from a reference point can cause dimensional changes in the cylinder components, which would likely result in stresses within the cylinder. These stresses can result from either transient or steady-state conditions of temperature and moisture, as shown by Newhouse[2].

6.1.2 Pressure

Working pressures typically range from 5 bar to 20 bar for liquified gas applications, and up to 1 100 bar for compressed gas applications, with allowance for pressure increases due to temperature increases. The maximum allowable working pressure in stationary applications, more commonly known as the design pressure or maximum service pressure for this application, is the maximum pressure the cylinder can be exposed to. The pressure may be at the design limit regardless of the service temperature.

In transportable and vehicle fuel container applications, the working pressure is the settled pressure at 15 °C, and can increase up to about 130 % of the rated working pressure during extreme temperature conditions. Operating pressures will be below the rated working pressure when ambient temperature drops below 15 °C. Note that in North America, the reference temperature is usually 21,1 °C (70 °F).

Cylinders in various applications can also be subject to test pressures that are generally 150 % of the rated working pressure, but can range from 125 % to 167 % of the rated working pressure, with generally not more than 50 such cycles over a lifetime. Although some cylinder standards or regulations allow pressurizing to test pressure during fill, cylinders should not be filled with more gas than would settle to working pressure at 15 °C.

6.1.3 Pressure cycles

Some applications require only a limited number of cycles in a lifetime, so fatigue evaluation is not a significant concern. Such applications include emergency breathing cylinders, and fuel containers for fuel cells providing power when primary power is out of service. It can also include applications where the cylinder is in limited use, and could only experience one or two pressure cycles in a month.

Transportable cylinders are generally designed for a specified lifetime, either limited or non-limited, and qualified by conducting a specified number of cycles. A typical qualification test requirement is 12,000 cycles to test pressure, or in dedicated gas service 24,000 cycles to maximum developed pressure, for a non-limited life. For a limited life, cycling 250 times to test pressure, or in dedicated gas service 500 times to maximum developed pressure, per year of design life is a common requirement. Specific standards could require more or less cycles. Transportable cylinders are generally not expected to be filled more than once a day, and cycling to the test pressure provides a margin of safety.

Vehicle fuel tanks, containing either natural gas or hydrogen, could be filled two to three times a day in fleet use, such as in buses or medium- and heavy-duty trucks. This is the basis for qualification testing of 750 cycles to 1 000 cycles per year used in fuel container standards.

Stationary cylinders, generally referred to as pressure vessels, could be subject to a high number of pressure cycles. One such application is use as a refuelling cascade for natural gas and hydrogen powered vehicles. These cylinders could be in use continually as vehicles are brought in for refuelling, resulting in a high number of cycles per day. In some cases, the cylinders could be refuelled from another fuel reservoir, such as from a pipeline, as soon as the pressure begins to drop. These cylinders can see a very high number of partial cycles. Some cylinders can see a high number of partial cycles, combined with a given number of full cycles, in the course of a day.

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