

CGA C-19—2008

**FRP-3—GUIDELINE FOR
FILAMENT-WOUND COMPOSITE
CYLINDERS WITH
NONLOADSHARING LINERS**

THIRD EDITION



Documents

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Work Item 06-012
Cylinder Specifications Committee

NOTE—Technical changes from the previous edition are underlined.

NOTE—Appendices A through G (Informative) are for information only.

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1 Scope

This guideline addresses the design, materials, and testing of fiber reinforced plastic (FRP) cylinders with liners carrying little or no load. These cylinders, limited in size to 6600 lb (3000 L) maximum water capacity, are intended for containment of compressed gases in general commercial service at pressures from 900 psig (6200 kPa) up to 15 000 psig (103.4 MPa) with a maximum service life of 30 years.^{1, 2} The qualification tests reflect the extreme service conditions that can be expected over the life of the cylinder in most applications. However, the manufacturer should determine if additional qualification testing is appropriate to address other service conditions that can be specific to a particular application.

2 Type, class, size, service life, and service conditions

2.1 Type

FRP-3 cylinders consist of resin impregnated, continuous filament windings in both longitudinal and circumferential directions over a liner that limits permeation of the contents of the cylinder. Liners for FRP-3 cylinders are designed to carry little or no load at operating pressure. FRP-3 cylinders are categorized into subtypes according to the kind of liner used. They are:

- FRP-3-1, thermoplastic lined;
- FRP-3-2, elastomeric lined;
- FRP-3-3, metal lined with integral bosses; and
- FRP-3-4, metal lined with bonded bosses.

2.2 Class

FRP-3 cylinders designed for a cycle life of 10 000 cycles or more are designated as Class A and are intended for general service. FRP-3 cylinders designed for a cycle life of 200 cycles to 9999 cycles are designated as Class B and are intended for special service.

2.3 Size

FRP-3 cylinders are limited to not more than 6600 lb (3000 L) water capacity. Manufacturers shall consider bending stresses in the design of cylinders with a length-to-diameter ratio greater than 10.

2.4 Service life

The manufacturer shall specify the service life of the cylinder subject to successful passing of any periodic inspections or tests. Maximum service life shall be 30 years.

2.5 Service pressure

Service pressure shall be at least 900 psig (6200 kPa) but not greater than 15 000 psig (103.4 MPa).

2.6 Service temperature

Cylinders shall be designed for service temperatures from $-40\text{ }^{\circ}\text{F}$ to $140\text{ }^{\circ}\text{F}$ ($-40\text{ }^{\circ}\text{C}$ to $60\text{ }^{\circ}\text{C}$). Materials of construction shall be suitable for exposure to temperatures up to $180\text{ }^{\circ}\text{F}$ ($82.2\text{ }^{\circ}\text{C}$).

¹ kPa shall indicate gauge pressure unless otherwise noted as (kPa, abs) for absolute pressure or (kPa, differential) for differential pressure. All kPa values are rounded off per [CGA P-11, Metric Practice Guide for the Compressed Gas Industry](#) [1].

² References are shown by bracketed numbers and are listed in order of appearance in the reference section.

3 Definitions

For the purpose of this publication, the following definitions apply.

3.1 Burst pressure

Highest pressure reached in a cylinder during a burst test.

3.2 Cylinder

Container for storing gases at high pressure configured as a right circular cylinder with end closures.

NOTE—The end closures are generally hemispherical in shape but may be either oblate or prolate.

3.3 Destroyed

Physically made unusable.

NOTE—For example, by drilling a hole in the cylinder or cutting it in half.

3.4 Elastic expansion

Difference in the volume (or displaced volume) of the cylinder measured at test pressure and at zero pressure after the hydrostatic test.

NOTE—See volumetric expansion.

3.5 Helical wrap

Composite reinforcement wound at a constant angle with respect to the longitudinal axis carrying the majority of the load in the longitudinal direction and part of the load in the hoop direction.

3.6 Hoop wrap

Composite reinforcement wound at a nominal angle of 90 degrees to the longitudinal axis that generally carries the major portion of the load in the hoop direction and little load in the longitudinal direction.

NOTE—Helical fibers wound at a high angle can be functionally equivalent to hoop fibers.

3.7 In-plane wrap

Composite reinforcement wound from end to end so the fiber path lies within a plane.

NOTE—It is also known as polar wrap.

3.8 Leakage

Release of contents through a defect or crack.

3.9 Liner

Inner container to which the overwrap is applied.

NOTE—The primary purpose of the liner is to prevent leakage or limit permeation of the gases through the cylinder wall.

3.10 Service pressure

Authorized pressure marking on the cylinder.

3.11 Test pressure

Maximum pressure to which a cylinder is taken during acceptance testing.

NOTE—Measurement of permanent volumetric expansion and total volumetric expansion are taken during this pressurization that shall last a minimum of 30 seconds.

3.12 Volumetric expansion

Change in internal (or displaced) volume of the cylinder during pressurization.

NOTE—Total volumetric expansion (VE) is the difference in the volume of the cylinder measured at test pressure and at zero pressure before the hydrostatic test. Permanent VE is the difference in the volume of the cylinder measured at zero pressure after the hydrostatic test and at zero pressure before the hydrostatic test. See elastic expansion.

4 Inspection requirements

4.1 Qualification and production

All inspections and verifications during qualification tests, lot acceptance tests, and manufacturing shall be performed by an independent inspector approved by the authority having jurisdiction.

4.2 Periodic in-service inspections

Each cylinder shall be visually inspected for external and internal damage and deterioration at time intervals as recommended by the manufacturer. The inspection shall be performed by an inspector approved by the authority having jurisdiction and in accordance with the manufacturer's established reinspection criteria and [CGA C-6.2, Guidelines for Visual Inspection and Requalification of Fiber Reinforced High Pressure Cylinders](#) [2]. Retest dates shall be marked on a label securely affixed to the cylinder near the original test date. Hydrostatic retesting is not required. Specific requalification criteria including assessment using nondestructive testing (NDT) and time intervals for inspection shall be developed as part of the design submission.

5 Duties of inspector

The following are duties of an inspector:

- Verify proper identification and compliance of all materials with the requirements specified by the manufacturer or in Section 6. Chemical analysis of metals may be verified by obtaining the producer's certified analysis. Verification may be by direct observation or by reviewing certification reports;
- Inspect interior and exterior surfaces of liners and completed cylinders to verify the absence of defects. Verify the minimum prescribed wall thickness and acceptability of welds, if present. Verification may be by direct measurement or observation or by reviewing inspection reports;
- Verify that composite materials meet the requirements of this standard and are in accordance with the composite structure present in the design and in the cylinders subject to the design qualification tests. This verification shall be accomplished by:
 - reviewing the manufacturer's quality control reports (see Section 7)
 - comparing liner weight versus final weight by sampling data or cylinders, or both
 - reviewing elastic expansion results (see 12.1)
 - witnessing a burst test and other tests as required;
- Verify compliance of threads by gauge. Verification may be by direct inspection or by reviewing inspection reports;
- Verify proper thermal treatment of materials by reviewing processes and certification reports;
- Report test results including total, elastic, and permanent expansion and test pressure for each cylinder. Report tare weight and volumetric capacity of each cylinder;
- Select all test samples, witness all tests, and obtain copies of all test results and certifications;
- Verify compliance of cylinders with all requirements including marking by inspection or reviewing certification reports;
- Witness the applicable design qualification tests specified in Section 19 and confirm that the test results are acceptable before the initial shipment of any cylinder design or design change; and
- Furnish complete inspector's report (Section 17) to the manufacturer of the cylinder.

6 Authorized materials

The manufacturer shall ensure that all materials are compatible with the expected external environments to which the cylinder is exposed, and all liner materials are compatible with the gases to be contained.

6.1 Thermoplastic liners

Thermoplastic materials may be used.

6.2 Elastomeric liners

Elastomeric materials may be used.

6.3 Metal liners

Metallic materials may be used provided they are not susceptible to stress corrosion cracking or other characteristics that would lead to premature failure.

6.4 Metal bosses

Materials shall be compatible with the liner and any bonding agents, with the intended environment, and shall be resistant to stress corrosion cracking to avoid failure during the life span of the cylinder.

6.5 Reinforcing fibers

Structural reinforcing filament material types shall be glass fiber, aramid fiber, or carbon fiber. Filament strength shall be certified as tested in [ASTM D2343](#), *Standard Test Method for Tensile Properties of Glass Fiber Strands, Yarns, and Rovings Used in Reinforced Plastics or an equivalent method suitable for the reinforcement fiber approved by the authority having jurisdiction [3]. Fiber coupling agents (sizing) shall be compatible with the resin system. If carbon fiber reinforcement is used, the design shall incorporate a means of preventing galvanic corrosion of metallic components of the cylinder.*

6.6 Resins

The resin system shall be tested on a sample coupon representative of the composite overwrap in accordance with ASTM D2344, *Standard Test Method for Short-Beam Strength of Polymer Matrix Composite Materials and Their Laminates* [4]. Testing shall follow a 24-hour water boil, and resins shall have a minimum shear strength of 2000 psi (13 790 kPa).

6.7 Adhesive bonding

Adhesive bonding of bosses to metallic or nonmetallic liners is acceptable.

6.8 Nonstructural materials

Nonstructural materials such as paints or protective coatings or wrappings may be used.

6.9 Traceability

All structural materials shall be traceable to their original manufacturer's certified test reports on a production lot basis.

6.10 Workmanship

The materials shall be of uniform quality. Materials with injurious defects are not authorized.

7 Manufacture

7.1 Plastic and elastomeric liners

A nonmetallic liner shall be as free of contaminants as necessary to afford a proper inspection. No defect is acceptable that is likely to cause the liner to leak within the required vessel lifetime. Interior folds, laps, or sharp surface indentations are not permitted. If not originally free from such defects, the liner surface may be re-worked to eliminate these defects provided the liner meets all design requirements afterwards.

7.2 Metal liners

Surfaces shall have dirt and scale removed as necessary to allow proper inspection. No defect is acceptable that is likely to weaken the finished cylinder. A reasonably smooth and uniform surface finish is required. No interior folding in the neck area is permitted, but smooth gathering of the material in the neck in which there are no sharp rooted folds is acceptable. If not originally free from these defects, the liner surface may be machined or otherwise treated to eliminate these defects provided the required minimum wall thickness is maintained.

7.3 Composite reinforcement

The cylinder shall be fabricated from a liner overwrapped with resin impregnated, continuous filament winding. The winding pattern is to be helical or in-plane and hoop wrap, applied under controlled tension to develop the design composite thickness. After the winding is complete, the composite shall be cured by a controlled temperature process. No defect is acceptable that is likely to weaken the finished cylinder appreciably.

The composite cylinder shall be designed so if the liner is susceptible to creep and flow when pressurized, no failure will occur during the prescribed lifetime.

An acceptable quality assurance program shall be defined for both the winding and the curing process to ensure that it can be repeated and traced.

The following parameters shall be defined, inspected, and noted:

- Percentages of the components of the matrix systems and their lot numbers. They shall be recorded, and all lots shall undergo acceptance testing;
- Lot numbers of the fibers used. They shall be recorded, and all lots shall undergo acceptance testing or be certified by their manufacturer;
- Number of strands used;
- Winding tension per strand or band (if applicable);
- Winding angles;
- Number and order of layers;
- Procedure followed to obtain correct impregnation in the case of wet winding; and
- Polymerization cycle and the polymerization process (for example, thermal cycle in an oven, ultrasound, ultraviolet, thermal radiation).

For thermal polymerization, the temperature and the length of the polymerization cycle of the resin system shall be such that they do not affect the mechanical characteristics of the liner. In addition, tolerances for holding time and temperature at each stage shall be maintained.

7.4 Bosses

Bosses shall be designed, in combination with the liner and overwrap, to resist torque loads needed to install valves and to resist axial loads that can be applied during service while the cylinder is not pressurized.

7.5 Welding

Welding is authorized on liners. The manufacturer shall use nondestructive examination methods, which are consistent with the materials and processes used on the welds. Welding procedures and operators shall be qualified in accordance with established guidelines for the materials and configurations being welded. Said procedures shall be written, controlled documents of the manufacturer that are reviewed and approved by the independent inspector.

7.6 Lot definitions

A cylinder lot shall be a group of cylinders successively produced from qualified liners or liner assemblies having the same size, configuration, specified materials of construction, and process of manufacture. A cylinder lot is any amount up to 200 units. Any unit processed for use in required destructive tests need not be counted against the numerical quantity limit of the lot but shall be representative of the lot.

The lot size of components other than cylinders (such as liners, bosses, pressure relief devices) shall be consistent with good manufacturing practice or requirements of other applicable standards.

A lot of cylinders may be fabricated using more than one lot of liners or other components.

7.7 Design qualification tests

Before initial shipment of any specific cylinder design, qualification tests as prescribed in Section 19 shall be performed with satisfactory results.

8 Wall thickness

8.1 Composite reinforcement

8.1.1 Stresses

Stresses in the composite reinforcement shall be calculated using engineering analysis. An acceptable method is to use the following equations:

$$\sigma_{\alpha} = P r / (2 \cos^2 \alpha t_{\alpha_f})$$

$$\sigma_{\theta} = P r [1 - (\tan^2 \alpha) / 2] / t_{\theta_f}$$

Where:

σ_{α} = stress in helical fibers

σ_{θ} = stress in hoop fibers

P = internal pressure

r = average radius of composite wall

α = helical wind angle

t_{α_f} = helical fiber thickness

t_{θ_f} = hoop fiber thickness

8.1.2 Design

The composite overwrap shall be designed for high reliability under sustained loading and cyclic loading. This reliability shall be achieved by meeting or exceeding the composite reinforcement stress ratio values that follow. The stress ratio is defined as the strength in the fiber (as demonstrated by stress in the fiber at minimum burst pressure) divided by the stress in the fiber at service pressure.

<u>Fiber</u>	<u>Stress ratio</u>
Glass	3.5
Aramid	3.0
Carbon	2.25

NOTE—The stress ratios given address high reliability under stress rupture and cyclic fatigue conditions with an allowance for some loss in strength over the lifetime of the cylinder. However, it is also necessary to pass all of the qualification tests in this standard for a cylinder to be safe. It is also necessary to understand the characteristics and limitations of the reinforcing fibers being used and conduct additional qualification tests as necessary. For example, glass and aramid fibers are affected by exposure to strong acids and bases, ultraviolet light, and high temperatures, while carbon fiber is more susceptible to impact damage than glass or aramid fiber. Therefore, for some applications, it might be advisable to conduct additional environmental or impact tests if the environment encountered is more severe than is identified by this standard.

8.1.3 Hybrid construction

If a hybrid construction with two or more types of reinforcing fibers is used, the stress ratio requirements shall be met in one of the following ways:

- If load sharing between the fibers is considered a fundamental part of the design, each of the fibers shall meet the stated stress ratio requirements. The equations in 8.1.1 shall be adjusted to reflect the relative thickness and stiffness of the different fibers to determine the amount of load carried in each fiber. The strength of the different fibers in a hybrid structure can be determined by burst testing cylinders reinforced with a single type of fiber; or
- If load sharing between the fibers is not considered a fundamental part of the design, then the structural reinforcing fiber(s) shall be capable of meeting their stress ratio requirements even if all of the nonstructural materials are removed.

8.1.4 Helical layers

If helical layers are wound at more than one helical wind angle, the equations in 8.1.1 shall be adjusted to reflect the relative thickness and stiffness of the different layers to determine the amount of load carried in each layer.

8.2 Liner thickness

The minimum thickness of the liner shall meet the required service life and cycle life requirements of this specification.

9 Openings

Openings are permitted in the heads only. The centerline of the polar boss shall coincide with the longitudinal axis of the cylinder.

Threads shall be clean cut, even, without checks, and to gauge.

Tapered threads are permitted.

Straight threads having at least six engaged threads and complying with the requirements of FED-STD-H28, *Screw Thread Standards for Federal Services* are permitted [5]. Other straight threads having at least six engaged threads are also permitted.