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ICS 23.020.30

CCS J 74

GB/T 42612-2023

Fully-wrapped carbon fiber reinforced cylinders with a plastic liner for the on-board storage of compressed hydrogen as a fuel for land vehicles

车用压缩氢气塑料内胆碳纤维全缠绕气瓶

(ISO 19881:2008, Gaseous hydrogen - Land vehicle fuel containers, NEQ)

Issued on: May 23, 2023 **Implemented on: June 01, 2024**

Issued by: State Administration for Market Regulation;
Standardization Administration of PRC.

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1 Scope

This document specifies the type, parameters, classification and model, technical requirements, test methods, inspection rules, installation, protection, marking, packaging, transportation and storage requirements of fully-wrapped carbon fiber reinforced cylinders with a plastic liner for the on-board storage of compressed hydrogen as a fuel for land vehicles (hereinafter referred to as cylinders).

This document is applicable to the design and manufacture of refillable cylinders, which have a nominal working pressure of 35 MPa and 70 MPa, a nominal volume greater than or equal to 20 L and not greater than 450 L, an operating temperature not lower than -40 °C and not higher than 85 °C, are fixed on motor vehicles for containing hydrogen fuel.

Hydrogen gas cylinders, which are used for hydrogen fuel cell urban rail transit, hydrogen ships, hydrogen aircraft, hydrogen power generation devices, etc., can refer to this document.

2 Normative references

The contents of the following documents constitute the essential provisions of this document through normative references in the text. For the dated documents, only the versions with the dates indicated are applicable to this document; for the undated documents, only the latest version (including all the amendments) is applicable to this standard.

GB/T 223.3 Methods for chemical analysis of iron, steel and alloy - The diantipyryl methane phosphomolybdate gravimetric method for the determination of phosphorus content

GB/T 223.4 Methods for chemical analysis of iron, steel and alloy - The volumetric method for determination of manganese content by ammonium nitrate oxidation

GB/T 223.5 Steel and iron - Determination of acid-soluble silicon and total silicon content - Reduced molybdosilicate spectrophotometric method

GB/T 223.11 Iron, steel and alloy - Determination of chromium content - Visual

5 Technical requirements and test methods

5.1 General requirements

5.1.1 Design service life

The design service life of the gas cylinder is 15 years.

5.1.2 Number of design cycles

The cylinders are designed for 11000 cycles.

5.1.3 Allowable pressure

During filling and use, the allowable pressure of the gas cylinder is 1.25 times the nominal working pressure.

5.1.4 Tolerance of test parameters

Unless otherwise specified, the test parameter tolerances shall comply with the provisions of Appendix A.

5.1.5 Temperature range

During filling and use, the temperature of the gas cylinder shall not be lower than -40 °C and not higher than 85 °C.

5.1.6 Hydrogen quality

The compressed hydrogen gas for filling cylinders shall meet the requirements of GB/T 37244.

5.1.7 Working environment

The design of gas cylinders shall consider its ability to continuously withstand mechanical damage or chemical erosion; its outer surface shall at least adapt to the following working environments:

a) Intermittent immersion in water or road splashing;

b) The vehicle is driven near the ocean or on roads where ice has been melted with salt;

c) UV radiation from sunlight;

d) Vehicle vibration or gravel impact;

e) Contact with acid solution, alkali solution, fertilizer;

f) Contact with automotive fluids, such as gasoline, hydraulic oil, battery acid, glycol and other greases;

g) Exposure to exhaust fumes.

5.1.8 Daily maintenance inspection

Routine maintenance and inspection shall be carried out within the service life of the gas cylinder; the basic method and technical requirements of the inspection shall comply with the provisions of Appendix B.

5.2 Materials

5.2.1 General requirements

5.2.1.1 The material properties shall comply with the relevant national standards or industry standards.

5.2.1.2 The material shall have the original quality certificate, which is provided by the material manufacturer, OR a copy of the quality certificate with the official seal of the material management organization and the signature (seal) of the person in charge.

5.2.1.3 The materials shall be re-inspected by the gas cylinder manufacturer, before they can be used.

5.2.2 Plastic liner

5.2.2.1 The plastic liner should be made of polyethylene (including modified polyethylene) or polyamide (including modified polyamide). Its compatibility with hydrogen shall meet the requirements of Appendix C.

5.2.2.2 The melting peak temperature of the plastic liner material shall be greater than or equal to the specified value in the design documents.

5.2.2.3 When the raw material of the plastic liner is granular, the melt mass flow rate of polyethylene (including modified polyethylene) and the melt volume flow rate of polyamide (including modified polyamide) shall meet the requirements of the design documents.

5.2.2.4 When the raw material of the plastic liner is powder, the apparent density, powder fluidity, particle size distribution shall meet the requirements of the design documents.

5.2.2.5 The gas cylinder manufacturer shall conduct re-inspection of the plastic liner material by batch. The melting peak temperature shall be measured, according to the test method specified in GB/T 19466.3, wherein the heating and cooling rate of polyethylene (including modified polyethylene) is 10 °C/min; the heating and cooling rate of polyamide (including modified polyamide) is 20 °C/min. When the raw material

of austenitic stainless steel S31603 and the tensile properties of aluminum alloy 6061, according to the material batch number. The tensile and impact tests of austenitic stainless steel S31603 are carried out, according to the provisions of GB/T 228.1 and GB/T 229, respectively; the tensile test of aluminum alloy 6061 is carried out, according to the provisions of GB/T 228.1.

5.2.4 O-ring seals

5.2.4.1 The material of O-ring seals shall be polymers, which have good compatibility with high-pressure hydrogen, such as silicone rubber, fluororubber, fluorosilicone rubber, fluorocarbon rubber, EPDM rubber or hydrogenated nitrile rubber.

5.2.4.2 The applicable temperature range of the O-ring material shall meet the requirements of -50 °C ~ 85 °C.

5.2.4.3 The material properties of O-ring seals shall meet the requirements of D.2 in Appendix D.

5.2.5 Resin

5.2.5.1 Epoxy resin or modified epoxy resin shall be used as impregnation resin matrix. The epoxy value or epoxy equivalent of the resin shall meet the requirements of the design documents; the glass transition temperature shall be greater than or equal to 105 °C.

5.2.5.2 The gas cylinder manufacturer shall re-inspect the resin by batch. The epoxy value is determined, according to GB/T 1677; the epoxy equivalent is determined, according to GB/T 4612; the glass transition temperature is determined, according to GB/T 19466.2.

5.2.6 Fiber

5.2.6.1 Carbon fiber

5.2.6.1.1 The mechanical properties of carbon fiber shall meet the requirements of the cylinder design documents.

5.2.6.1.2 The gas cylinder manufacturer shall re-inspect the carbon fiber by batch. Carbon fiber linear density and fiber dipped tensile strength shall be measured, according to GB/T 3362; the specimen shall be prepared without twisting.

5.2.6.2 Fiberglass

The glass fiber protective layer of gas cylinders shall use S glass fiber or E glass fiber.

5.3 Design

5.3.1 Carbon fiber, plastic liner, cylinder valve seat

5.3.1.1 Carbon fibers shall be continuous, untwisted, of the same strength level.

5.3.1.2 The plastic liner shall have no longitudinal welded joints; meanwhile the circumferential welded joints shall be less than or equal to two.

5.3.1.3 The static strength, fatigue life of the valve seat of the cylinder, as well as the static strength, fatigue strength, sealing performance of the connection joint with the plastic liner shall meet the safety requirements, during the whole life of the gas cylinder.

5.3.1.4 The valve seat of the cylinder shall be at the end of the plastic liner AND shall be coaxial with the plastic liner.

5.3.1.5 The thread of the cylinder mouth shall match the thread of the cylinder valve; the thread of the cylinder mouth shall adopt the straight thread in accordance with GB/T 192, GB/T 196, GB/T 197 or GB/T 20668. The thread length shall be greater than the effective length of the cylinder valve thread.

5.3.1.6 The shear stress safety factor of the cylinder mouth thread under the hydraulic test pressure shall be greater than or equal to 4. When calculating the safety factor of thread shear stress, the shear strength is taken as 0.6 times the guaranteed value of the material tensile strength.

5.3.1.7 The design of the cylinder mouth shall consider the sealing material, sealing form, sealing structure size of the cylinder valve to be assembled. Reasonable dimensional tolerance and surface roughness shall be determined, to ensure that the cylinder mouth and cylinder valve are assembled in categories A1 and B1 gas cylinders. There is no leakage during the period of regular inspection of categories A2 and B2 gas cylinders during the whole life.

5.3.2 Gas cylinders

5.3.2.1 The hydraulic test pressure of gas cylinders shall be greater than or equal to 1.5 times the nominal working pressure.

5.3.2.2 When designing the gas cylinder, a finite element analysis model of the gas cylinder shall be established, to calculate the stress and strain of the carbon fiber winding layer and the cylinder valve seat, under the following pressures: nominal working pressure, hydraulic test pressure, minimum design burst pressure. The finite element analysis model of the gas cylinder shall be able to characterize the geometric characteristics, material properties, boundary conditions of the gas cylinder.

Note: The gas cylinder adopts a test-oriented design method based on finite element analysis.

5.3.2.3 The fiber stress ratio and minimum design burst pressure of gas cylinders shall meet the requirements in Table 3.

5.4.4.4 Monitor the curing process and record the time, temperature, internal pressure.

5.5 Accessories

5.5.1 The cylinder valve shall meet the requirements of GB/T 42536.

5.5.2 Gas cylinders shall be installed with TPRD. TPRD shall use fusible alloy plug or glass bubble; its operating temperature is (110 ± 5) °C. Fusible alloy plugs shall meet the requirements of GB/T 33215; glass bulbs shall meet the requirements of relevant standards. The TPRD drain shall not face the cylinder.

5.5.3 The safe discharge capacity of the gas cylinder and the rated discharge capacity of the pressure relief device shall be calculated, according to GB/T 33215, where the discharge coefficient may be 0.975. For category B gas cylinders and category A gas cylinders with a nominal volume greater than 100 L, the rated displacement of the pressure relief device can be calculated, based on the actual discharge diameter plus 1.5 mm; meanwhile the rated displacement of the pressure relief device can be verified by the fire test specified in 5.7.7, to check whether it meets the safety discharge requirements of gas cylinders.

5.5.4 When installing other protective devices, supporting devices and fixing devices on the gas cylinder, the devices shall not affect the force on the gas cylinder and the normal opening of the TPRD.

5.5.5 The accessories of categories A1 and B1 gas cylinders shall meet the requirements for safe use of gas cylinders, without disassembly and inspection during the whole life of the gas cylinders.

5.5.6 The blind plug material shall be the same as that of the cylinder valve seat.

5.6 Eligibility indicators and test methods of the liner

5.6.1 Quality, wall thickness, manufacturing deviations

5.6.1.1 Eligibility indicators

The quality, wall thickness, manufacturing deviation of the plastic liner shall meet the following requirements:

a) The mass is greater than or equal to the design mass;

b) The wall thickness is greater than or equal to the design wall thickness;

c) The difference -- between the average outer diameter of the cylinder and the nominal outer diameter -- is less than or equal to 1% of the nominal outer diameter;

d) The difference -- between the largest outer diameter and the smallest outer diameter -- on the same section of the cylinder, is less than or equal to 2% of the nominal outer diameter;

e) The straightness of the cylinder is less than or equal to 0.3% of the length of the cylinder.

5.6.1.2 Test method

The mass, wall thickness, manufacturing deviation of the plastic liner shall be checked by the following methods.

a) The mass shall be measured by weighing instruments, such as electronic digital scales. The maximum weighing capacity of the weighing instrument shall be 1.5 times ~ 3 times the commonly used weighing value; the allowable error shall meet the requirements of the medium accuracy level, which is specified in Table 1 of JJG 539-2016.

b) The wall thickness should be measured by an ultrasonic thickness gauge or other measuring instruments/tools, whose measurement accuracy is equivalent to that of an ultrasonic thickness gauge; the measurement accuracy shall not be lower than 0.1 mm.

c) Manufacturing deviations shall be checked by special measuring tools.

5.6.2 Internal and external surfaces

5.6.2.1 Eligibility indicators

The inner and outer surfaces of the plastic liner shall meet the following requirements:

a) Clean and free from dirt;

b) There are no defects such as bulges, wrinkles, overlaps, surface indentations with sharp edges.

5.6.2.2 Test method

Visually inspect the outer surface under sufficient light. Use an endoscopic lamp or an industrial endoscope to inspect the inner surface, if necessary.

5.6.3 Base metal tensile test

5.6.3.1 Eligibility indicators

The failure type of the specimen is ductile fracture. The tensile fracture stress and tensile fracture nominal strain shall be greater than or equal to the design guarantee value of the gas cylinder manufacturer.

Note: It is sometimes difficult to judge ductile fracture and brittle fracture, so comprehensive consideration of tensile fracture nominal strain, fracture macroscopic and microscopic morphology is helpful for judging the type of fracture.

5.6.4.2.1 Eligibility indicators

The fusion width shall meet the requirements of the design documents.

5.6.4.2.2 Test method

For the remaining welded joints after the tensile specimens were taken, first cut each welded joint along the axial direction, at four positions of 45°, 135°, 225°, 315° in the circumferential direction, as shown in Figure 3. Use an optical microscope, which has a measurement system, to observe the melting range of the melting part; meanwhile measure the melting width, at a measurement accuracy of 0.1 mm.

5.6.5 Vicat softening temperature

5.6.5.1 Eligibility indicators

The Vicat softening temperature of polyethylene (including modified polyethylene) shall be greater than or equal to 115 °C. The Vicat softening temperature of polyamide (including modified polyamide) shall be greater than or equal to 135 °C.

5.6.5.2 Test method

Measure it, according to the A_{50} method specified in GB/T 1633-2000.

5.6.6 Cylinder valve seat

5.6.6.1 Cylinder seat threads

5.6.6.1.1 Eligibility indicators

The cylinder valve seat thread meets the following requirements:

a) The number of effective pitches of the thread shall comply with the provisions of the gas cylinder design documents;

b) The thread profile, size, tolerance, surface roughness shall comply with the provisions of the gas cylinder design documents.

5.6.6.1.2 Test method

Under sufficient light, use a gauge to visually inspect the thread of the cylinder valve seat. The gauge shall match the thread of the cylinder valve seat. It should use the standard gauge in accordance with GB/T 3934 for inspection; the surface roughness shall be inspected with a roughness meter.

5.6.6.2 Cylinder valve seat and plastic liner connecting joint

5.6.6.2.1 Eligibility indicators

The quality inspection of the joint -- between the cylinder valve seat and the plastic

liner -- shall at least include size (only for the case where the plastic liner is molded and then assembled with the cylinder valve seat), low-pressure airtightness, cutting inspection. The quality of the joint -- between the cylinder valve seat and the plastic liner -- shall meet the requirements of the gas cylinder design documents.

5.6.6.2.2 Test method

The test method is as follows:

a) Dimensional inspection: It should use optical equipment to inspect the dimensions of the connecting joints, through non-contact measurement methods; the measurement accuracy shall not be lower than 0.1 mm;

b) Low-pressure airtightness inspection: Use oil-free clean dry air or other inert gases, to conduct low-pressure airtightness inspections. The test pressure shall be less than or equal to 0.2 MPa. The holding time shall be greater than or equal to 1 min. Other parameters shall be designed according to the cylinder design documents;

c) Cutting inspection: After dissecting the joint between the valve seat of the cylinder and the plastic liner according to the requirements of the process document, conduct a visual inspection under sufficient light.

Note: Computerized tomography (CT) inspection has the advantage of not destroying the gas cylinder, so it is a method that may replace visual inspection in the future.

5.6.7 O-ring seals

5.6.7.1 Eligibility indicators

The appearance, size, hardness, tensile strength at break, elongation at break, compression set, hardness change, hydrogen damage of the O-ring shall meet the requirements of D.3.

5.6.7.2 Test method

Carry out the test according to the provisions of D.3. The compression set test, hardness change test, hydrogen damage test shall be conducted by the O-ring manufacturer or the gas cylinder manufacturer and provide a test report. The gas cylinder manufacturer shall re-inspect the appearance, size, hardness of the O-ring.

5.7 Cylinder eligibility indicators and test method

5.7.1 Mechanical properties of winding layer

5.7.1.1 Interlaminar shear test

5.7.1.1.1 Eligibility indicators

The internal testing method is adopted; the test is carried out according to the provisions of GB/T 9251. The test pressure P_h is 1.5 times the nominal working pressure; the pressure holding time is at least 30 s.

5.7.4 Air tightness test

5.7.4.1 Eligibility indicators

The hydrogen leak rate shall be less than or equal to 6 mL/(h·L).

5.7.4.2 Test method

Use the gas cylinders that have passed the hydrostatic test. Conduct the test according to the provisions of Appendix H, at a temperature of (15 ± 5) °C.

5.7.5 Hydraulic burst test

5.7.5.1 Eligibility indicators

The burst pressure of the gas cylinder shall be $0.9P_{b0}$ ~ $1.1P_{b0}$, and greater than or equal to P_{bmin}. The expected value P_{b0} of the gas cylinder burst pressure and the basis for its determination (including the measured value and its statistical analysis) shall be provided by the gas cylinder manufacturer.

5.7.5.2 Test method

Carry out the test, according to the provisions of GB/T 15385. During the test, the pressurization rate meets the following requirements at the same time:

a) When the test pressure is greater than 1.5 times the nominal working pressure, the pressure increase rate shall be less than or equal to 1.4 MPa/s;

b) When the pressure increase rate is less than or equal to 0.35 MPa/s, it can be pressurized until it explodes. When the pressure increase rate is more than 0.35 MPa/s and less than 1.4 MPa/s, if the cylinder is between the pressure source and pressure test device, it can be pressurized until it bursts; otherwise, it shall be kept under the minimum design bursting pressure for at least 5 s, then continue to pressurize until it bursts.

5.7.6 Normal temperature and pressure cycle test

5.7.6.1 Eligibility indicators

The cylinders of categories A1 and B1 shall not leak or break within 22000 cycles; the cylinders shall not break, if they continue to cycle to 44000 or leak. Categories A2 and B2 gas cylinders shall not leak or break, within the design cycle number of 11000; the gas cylinders shall not break if the cycle continues to 22000 or until leakage.

5.7.6.2 Test method

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