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BUREAU OF INDIAN STANDARDS

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भारतीय मानक **मसौदा**

ऑटोमोटिव वाहनों के लिए ईंधन के रूप में संपीड़ित हाइड्रोजन गैस और हाइड्रोजन मिश्रित ऑन-बोर्ड स्टोरेज के लिए सिलिंडर — विशिष्टि

(IS 16735 का *पहला पुनरीक्षण)*

Draft *Indian Standard*

CYLINDERS FOR ON-BOARD STORAGE OF COMPRESSED GASEOUS HYDROGEN AND HYDROGEN BLENDS AS A FUEL FOR AUTOMOTIVE VEHICLES — SPECIFICATION

(First revision of IS 16735 *)*

ICS 23.020.30; 43.060.40

Gas Cylinders Sectional Committee, MED 16	Last date for receipt of comments is **16 March 2024**

FOREWORD
(*Formal clause to be added later*)

Cylinders for on-board storage of compressed gaseous hydrogen and hydrogen blends as fuels for automotive vehicle service are required to maintain or improve the level, of safety currently existing for automotive vehicle applications. These requirements are achieved by:

a) Specifying service conditions precisely and comprehensively as a firm basis for both cylinder design and use;
b) Using an appropriate method to assess cyclic pressure fatigue life and to establish allowable defect sizes in metal tanks or liners;
c) Requiring design qualification tests;
d) Requiring non-destructive testing and inspection of all production cylinders;
e) Requiring destructive tests on cylinders and tank material taken from each batch of cylinders produced;
f) Requiring manufacturers to specify the acceptable in-service damage levels for their design; and
g) Requiring manufacturers to specify as part of their design, the safe service conditions for their cylinders.

Designs meeting the requirements of this Indian Standard.

a) Will have a fatigue life that exceeds the expected service; and
b) Will demonstrate appropriate strength and durability for expected service conditions.

Owners and users of cylinders should note that cylinders should note that cylinders designed to this standard are to operate safely, if used in accordance with specified service conditions. It is the responsibility of the owners and users to ensure that cylinders are periodically tested as per norms laid down in *Gas Cylinder Rules*, 2016 as amended from time to time and as enforced by the statutory authority. While implementing this standard, the manufacturer and the inspection agency shall ensure compliance with statutory regulations.

In the formulation this standard, considerable assistance has been derived from ISO 19881 : 2018 'Gaseous hydrogen — Land vehicle fuel containers'.

The relevant SI units and corresponding conversion factors are given below for guidance:

1 kgf/cm^2 = 98.066 5 kPa (kilopascal) = 10 m of water column (WC)
= 0.098 066 5 MPa
= 0.980 665 bar Pressure 1Pa (Pascal)
= 1 N/m^2

The composition of the committee, responsible for the formulation of this standard is given at (*to be added later*).

For the purpose of deciding whether a particular requirement of this standard is complied with the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 2022 'Rules for rounding off numerical values (*second revision*). The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Draft *Indian Standard*

CYLINDERS FOR ON-BOARD STORAGE OF COMPRESSED GASEOUS HYDROGEN AND HYDROGEN BLENDS AS A FUEL FOR AUTOMOTIVE VEHICLES — SPECIFICATION

(First Revision)

1 SCOPE

1.1 This standard specifies the requirements for refillable cylinders of water capacity not exceeding 1 000 litre intended only for the on-board storage of high- pressure compressed gaseous hydrogen or hydrogen blends on automotive vehicles. This standard is applicable for cylinders of steel, aluminium or non- metallic construction material, using any design or method of manufacture suitable for its specified service conditions. This standard applies to the following types of cylinder designs:

a) *Type* 1 — Metal cylinders;
b) *Type* 2 — Hoop wrapped cylinders;
c) *Type* 3 — Fully wrapped composite cylinders with a metal liner; and
d) *Type* 4 — Fully wrapped composite cylinders with a nonmetallic liner.

1.2 This standard is not applicable for cylinders used for solid, liquid hydrogen, or hybrid cryogenic high- pressure hydrogen storage applications.

2 REFERENCES

The standards listed in Annex A contain provisions which through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards listed in Annex A.

3 TERMINOLOGY

For the purpose of this standard, the terms given in IS 7241 and the following shall apply.

3.1 Authorized Inspection Authority — An inspection agency having qualification and wide experience in the field of design, manufacture, and testing of gas cylinders and recognized by the statutory authority for inspection and certification of gas cylinders.

3.2 Autofrettage — Pressure application procedure used in manufacturing composite cylinders with metal liners, which strains the liner past its yield point sufficient to cause permanent plastic deformation. This results in the liner having compressive stresses and the fibres having tensile stresses at zero internal pressure. Autofrettage is a part of the manufacturing operation and is conducted on the metal lined filament wound cylinders prior to hydrostatic pressure testing.

3.3 Autofrettage Pressure — Pressure within the over-wrapped cylinder at which the required distribution of stresses between the liner and the over-wrap is established.

3.4 Batch (of Composite Cylinders) — Group of cylinders successively produced from qualified liners having the same size, design, specified material of construction, and process of manufacture. A batch shall be a group of not more than 200 cylinders plus cylinders for destructive testing.

3.5 Batch (of Metallic Liners) — Group of liners successively produced having the same heat number, nominal diameter, wall thickness, design, specified material of construction, process of manufacture, equipment for manufacture and heat treatment, and conditions of time, temperature and atmosphere during heat treatment. The batch shall be a group of not more than 200 liner plus liners for destructive testing.

3.6 Batch (of Non-metallic Liners) — Group of non-metallic liners successively produced having the same nominal diameter, wall thickness, design, specified material of construction, process of manufacture. A batch shall be a group of not more than 200 liner plus liners for destructive testing or one shift of successive production, whichever is greater.

3.7 Burst Pressure — The highest pressure reached in a cylinder during a burst test.

3.8 Composite Cylinder — Cylinder made of resin-impregnated continuous filament wound over a metallic liner.

NOTE — Composite cylinders using non-metallic liners are referred to as all composite cylinders (Type-4).

3.9 Controlled Tension Winding — Process used in manufacturing hoop-wrapped composite cylinders with metal liners by which compressive stresses in the liner and tensile stresses in the over-wrap at zero internal pressure are obtained by winding the reinforcing filaments under significant high tension.

3.10 Cylinder Category — Unique class of cylinders that are intended for a specific usage

3.10.1 *Category A* — Class of cylinders that are intended to be used in light duty and heavy duty land vehicle applications, regardless of the potential for further qualification to the UN GTR No. 13 for hydrogen and fuel cell vehicles

3.10.2 *Category B* — Class of Type 4 cylinders [*see* **1.1** (d)] of 70 MPa nominal working pressure that are intended to be further qualified in accordance with the UN GTR No. 13 for hydrogen and fuel cell vehicles with a gross vehicle mass of 4 536 kg or less.

3.10.3 *Category C* — Class of cylinders that are intended to be used on hydrogen powered industrial trucks.

3.11 Design Change — Change in structural materials, working pressure, dimensional changes exceeding the tolerances as on the design drawings and falling under the category of design change in **9.4**.

3.12 Finished Cylinders — Completed cylinders which are ready for use, typical of normal production, complete with identification marks and external insulation, as specified by the manufacturer, but free from non-integral insulation or protection.

3.13 Full Wrapped Cylinder — Cylinder with an overwrap having filament wound reinforcement both in the circumferential and axial direction of the cylinder over the entire liner including the domes.

3.14 Hoop Wrapped Cylinder — Cylinder with an overwrap having filament wound reinforcement in the circumferential direction of the cylinder over the cylindrical portion of the liner.

3.15 Gas Temperature — Temperature of gas in a cylinder

3.16 Hydrogen Blend — A mixture of natural gas and more than 2 percent by volume of hydrogen.

3.17 Hydrogen and Hydrogen-Blend Storage System — System on an automotive vehicle comprised of the cylinder and all closure devices (for example, shut-off valves, check valves and pressure activated and thermal activated pressure relief devices), as well as piping that contains hydrogen and hydrogen-blend at the working pressure. The pressure relief device and thermal relief device should be activated independently.

3.18 Leakage — Release of gas through a crack, pore, unbounded or similar defect.

3.19 Liner — Gas-tight inner shell, on which reinforcing fibres are filament wound to reach the necessary strength. Two types of liner are described in this Standard; metallic and non-metallic liners. Metallic liners are designed to share the load with the reinforcement and non-metallic liners do not carry any part of the load.

3.20 Manufacturer — Person or organization responsible for the design, fabrication, and testing of the cylinders.

3.21 Overwrap — Reinforcement system of filament and resin applied over the liner.

3.22 Pre-stress or Pre-stressing — The process of applying auto-frettage or controlled tension winding.

3.23 Service Conditions — Conditions that the cylinder will experience in service and that include on-road exposure to environmental factors (road salt, acids, alkalies, temperature extremes) and expected usage (gas composition, impurities in the gas and any odorizing agent added in the gas as well as pressure cycles associated with filling and discharge during service and driving, static pressure associated with vehicle parking, etc).

3.24 Service Life — Life, in years, during which the cylinders may safely be used in accordance with the standard service conditions.

3.25 Settled Pressure — Gas pressure when a given settled temperature is reached.

3.26 Settled Temperature — Uniform gas temperature after the dissipation of any change in temperature caused by filling.

3.27 Stress Ratio — Stress in fibre at specified minimum burst pressure divided by stress in fibre at working pressure.

3.28 Test Pressure — Test pressure means the internal pressure required for the hydrostatic test or hydrostatic stretch test of the cylinder. It shall be 1.5 × working pressure of cylinder except for Type 1 cylinders manufactured conforming to IS 7285 (Part 2).

3.29 Thermally Activated Pressure Relief Device — Device that activates by temperature to release pressure and prevent a cylinder from bursting due to fire effects and that will activate regardless of cylinder pressure.

3.30 Working Pressure — Settled pressure of 200 bar, 250 bar, 350 bar, 500 bar, and 700 bar at a uniform temperature of 15 °C.

4 SERVICE CONDITIONS

4.1 General

The specified service conditions provide the basis for the design, manufacturing, inspection, and testing of cylinders that are to be mounted on automotive vehicles and used to store compressed gaseous hydrogen or hydrogen blends at ambient temperatures for use as a fuel for these vehicles.

The specified service conditions are also intended to provide information on how cylinders made in accordance with this standard may safely be used by.

a) Manufacturers of cylinders;
b) Owners of cylinders;
c) Users of cylinders;
d) Designers or contractors responsible for the installation of cylinders;
e) Designers or owners of equipment used to refuel automotive vehicle cylinders;
f) Suppliers of gaseous hydrogen and hydrogen blends;
g) Regulatory authorities that have jurisdiction over cylinder use; and
h) Cylinder mounting arrangement considered by the manufacturer at the time of design.

The service conditions do not cover external loading that may arise from vehicle collisions, etc.

For cylinders involved in collision or fire, guidance may be taken from Annex B.

4.2 Service Life

The service life for which cylinders are safe shall be specified by the cylinder manufacturer on the basis of use under service conditions specified therein. Periodic testing and recertification of cylinders to be done as per statutory requirements. Service life shall not be less than 10 years. The maximum service life shall be 20 years.

For metal cylinders and metal-lined cylinders, the service life shall be based upon the rate of fatigue crack growth. The ultrasonic inspection, or equivalent, of each cylinder or liner shall ensure the absence of flaws which exceed the maximum allowable size. The method shall as per Annex C.

For composite cylinders with non-metallic, non-load bearing liners the service life shall be demonstrated by appropriate design methods, design qualification testing and manufacturing controls.

4.3 Maximum Filling Pressure

This standard is based upon a working pressure of 200 bar, 250 bar, 350 bar, 500 bar, and 700 bar settled at 15 °C for hydrogen and hydrogen blends as a fuel with a maximum filling pressure of 125 percent of working pressure. Other working pressures may be accommodated by adjusting the relevant test pressures by the appropriate factor (ratio); for example, a 250 bar working pressure system will require filling pressures to be multiplied by 1.25. Except where pressures have been adjusted in this way, the cylinder shall be designed to be suitable for the following pressure limits:

a) A pressure that would settle to 200 bar, 250 bar, 350 bar, 500 bar, and 700 bar at a settled temperature of 15 °C; and
b) The maximum pressure shall not exceed 125 percent of working pressure regardless of filling conditions or temperature.

4.4 Maximum Number of Filling Cycles

4.4.1 *General*

Cylinders shall be designed for filling gas at pressure not exceeding the requirements of **4.3** as following. For calculation, guidance may be taken from Annex D.

a) Category A: For a maximum of 750 times the service life of the cylinder in years for a minimum of 10 years and a maximum of 25 years;
b) Category B: For a maximum of 5 500, 7 500, or 11 000 for a 15 year service life; and
c) Category C: For a maximum of 1 125 times the service life of the cylinder in years for a minimum of 10 years and a maximum of 25 years.

4.5 Design Temperature

Cylinders shall be designed to be suitable for use in the material temperature range −40 °C to +85 °C during filling and discharge.

a) Compressed natural gas (CNG) used in hydrogen blends shall comply with the dry gas composition limits specified in IS 15490.

4.6 Gas Composition

Cylinders shall be designed to be filled with compressed gaseous hydrogen and/or hydrogen blends containing more than 2 percent hydrogen by volume, combined with dry natural gas. The gas composition shall comply with the following:

a) Compressed hydrogen gas shall comply with the composition specified in IS 16061; and
b) Compressed Natural Gas (CNG) used in hydrogen blends shall comply with the dry gas composition limits specified in IS 15490.

4.7 External Surfaces

Cylinder external surfaces shall be designed to be resistant to environmental conditions outlined in **H-8.**

4.8 Installation Requirements

The cylinder manufacturer shall provide information to the vehicle manufacturer or system integrator as necessary to support proper installation in the vehicle.

The vehicle manufacturer or system integrator shall be responsible for the protection of the cylinder, cylinder valves, pressure relief devices, and connections as required.

If this protection is mounted to the cylinder, the design and method of attachment shall be approved by the cylinder manufacturer. Factors to be considered include the ability of the cylinder to support the transferred impact loads and the effect of local stiffening on cylinder stresses and fatigue life.

Cylinders shall be protected from accidental cargo spillage and from mechanical damage. This document contains no requirements for cylinder integrity in a vehicle collision. Cylinder locations and mountings should be designed to provide adequate impact protection to prevent cylinder failure in a collision.

4.9 Fire Effects

Cylinders shall be protected from fire effects using non-reclosing thermally activated pressure relief devices or non-reclosing pressure-activated relief device. Non-reclosing pressure-activated pressure relief devices shall only be used in parallel with thermally activated pressure relief devices. Under no circumstances shall a thermally activated pressure relief device require the operation of the pressure activated pressure relief device in order to function.

The fire protection of cylinders may also be supplemented by the use of thermal insulation. This arrangement shall be such that bare cylinders are available for periodic inspection.

5 APPROVAL AND CERTIFICATION

5.1 Inspection and Testing

In order to ensure that the cylinders are in compliance with this standard they shall be subjected to design approval in accordance with **5.2.2**, and inspection and testing in accordance with **9.2** or **9.4** as appropriate.

5.2 Type Approval Procedure

5.2.1 *General*

Type approval consists of following parts:

a) The design submission comprising of information furnished by the manufacturer to the inspector for appraisal/scrutiny and further recommendations to the statutory authority for approval, as detailed in **5.2.2**; and
b) Prototype testing, comprising testing carried out under the supervision of the inspector. The cylinder material, design, manufacture and examination shall be proved to be adequate for their intended service by meeting the requirements of the prototype tests specified in **9.2** or **9.4** as appropriate for the particular cylinder design.

The test data shall also document the dimension, wall thicknesses and weights of each of the test cylinders.

5.2.2 *Design Approval*

Cylinder designs shall be approved by the statutory authority. The following information shall be submitted by the manufacturer to the inspector for examination and further approval by statutory authority.

a) Statement of service, in accordance with **5.2.3**;
b) Design data, in accordance with **5.2.4**;
c) Manufacturing data, in accordance with **5.2.5**;
d) Fracture performance and NDE (non-destructive examination) defect size, in accordance with **5.2.6**;
e) Specification sheet, in accordance with **5.2.7**;
f) Additional supporting data, in accordance with **5.2.8**; and
g) Quality system, in accordance with **5.2.9**.

5.2.3 *Statement of Service*

The purpose of this statement of service is to guide the user and the installer of cylinders as well as to inform the inspector. The statement of service shall include.

a) The name and address of the cylinder manufacturer;
b) A description of the cylinder design, including cylinder identification, working pressure (MPa), cylinder type, diameter (mm), length (mm), internal volume (l), empty weight (kg) and valve thread type; a statement that the cylinder design is suitable for use in the service conditions provided in **4**;
c) A statement of the maximum number of filling cycles for which the cylinder is designed;
d) A statement of the service life;
e) A specification for minimum in-service inspection and testing requirements;
f) A specification for the pressure relief devices;
g) A specification for the support methods, protective covering and any other items required but not provided;
h) A description of the cylinder design;
j) Information regarding approval including date and approving agency. Periodic retesting interval; and
k) Any other information necessary to ensure the safe use and inspection of the cylinder.

5.2.4 *Design Data*

5.2.4.1 *Drawings*

Drawings shall show at least the following:

a) Title, reference number, date of issue, and revision numbers with dates of issue, if applicable;
b) Reference to this standard and the cylinder type reference as Type 1, Type 2, Type 3, or Type 4 design;
c) All dimensions complete with tolerances, including details of end closure shapes with minimum thicknesses and of openings;
d) Mass, complete with tolerance of cylinders;
e) Material specifications, complete with minimum mechanical and chemical properties or tolerance ranges and, for metal liners, the specified hardness range;
f) Gas or gas blends that the cylinder is designed to carry;

g) Working pressure; and
h) Other data such as, auto-frettage pressure range, minimum test pressure, and of any exterior protective coating.

5.2.4.2 *Stress analysis report*

When a stress analysis is required to be carried out, the stress analysis report shall be kept on file and shall include a table summarizing the calculated stresses.

NOTE — Verification of the stress ratios shall be performed using strain gauges or an equivalent method. An example of an acceptable method is provided in Annex C.

5.2.4.3 *Material property data*

A detailed description of the materials and tolerances of the materials properties used in the design shall be provided. Test data shall also be presented characterizing the mechanical properties and the suitability of the materials for service under the conditions specified in **4**.

5.2.4.4 *Fire protection*

The arrangement of the non-reclosing thermally activated pressure relief devices, and insulation, if provided, that will protect the cylinder from sudden rupture when exposed to the fire conditions in **H-7** shall be specified by the cylinder manufacturer. Test data shall substantiate the effectiveness of the specified fire protection system.

5.2.5 *Manufacturing Data*

Details of all fabrication processes, tolerances, non-destructive examinations, type tests, batch tests, and production tests shall be specified and kept on file by the cylinder manufacturer. The tolerances for all production process such as heat treatment, end forming resin-mix ratio, complete winding details, curing times and temperatures, and auto-frettage procedures, surface finish, thread details, acceptance criteria for ultrasonic scanning (or equivalent) and maximum lot sizes for batch tests shall also be specified.

The manufacturer shall specify the minimum burst pressure for the design. In no case shall the minimum specified burst pressure be less than the minimum burst pressure specified in this standard.

5.2.6 *Fracture Performance and Non-destructive Examination (NDE) Defect Size*

The manufacturer shall specify the maximum defect size for non-destructive examination which will ensure leak before break (LBB) fracture performance and will prevent failure of the cylinder during its service life due to fatigue, or failure of the cylinder by rupture.

The maximum defect size shall be established by a method suitable to the design; an example of a suitable method is given in Annex E.

5.2.7 *Specification Sheet*

A summary of the documents providing the information required in **5.2.2** shall be listed on a specification sheet for each cylinder design. The title, reference number, revision numbers and dates of original issue and version issues of each document shall be given. All documents shall be signed or initialled by the issuer. The specification sheet shall be given a number and revision numbers if applicable, that can be used to designate the cylinder design and shall carry the signature of the engineer responsible for the design. Space shall be provided on the specification sheet for a stamp indicating registration of the design.

5.2.8 *Additional Supporting Data*

Additional data which would support the application, such as the service history of material proposed for use, or the use of a particular cylinder design in other service conditions shall be provided where applicable.

5.2.9 *Quality Management System*

The manufacturing plant shall operate a quality management system in compliance with National or International Standards.

5.3 Type Approval Certificate

If the results of the design approval according to **5.2** and the prototype testing according to **9.2** or **9.4** are satisfactory, the inspector shall foreword the test report for approval of the statutory authority (a typical example is given in the Annex F).

6 MATERIALS

6.1 Compatibility

Materials used shall be suitable for the service conditions specified in **4**. The design shall not have incompatible materials in contact with each other. All metallic materials in contact with hydrogen and hydrogen blends shall be compatible with hydrogen according to **H-2**.

Table 1 summarizes specific material tests that are required herein subsequently.

Table 1 Material Tests

(*Clause* 6.1)

Sl No.	**Material Tests**	**Clause**	**Material Type**	**Cylinder Type**			
				1	**2**	**3**	**4**
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	Impact test	**6.4**	Steel	•	•	•	•
ii)	Tensile test	**6.5**	Metals	•	•	•	•
iii)	Sustained load cracking test	**6.2.2**	Aluminum	•	•	•	•
iv)	Corrosion test	**6.2.2**	Aluminum	•	•	•	•
v)	Ultraviolet resistance test	**6.6**	External coatings	•	•	•	•

vi)	Shear strength test	**6.3**	Resins	•	•	•
vii)	Glass transition temperature test	**6.3**	Resins	•	•	•
viii)	Tensile test	**6.2.3**	Non-metallic liners			•
ix)	Softening temperature test	**6.2.3**	Non-metallic liners			•
x)	Tensile test	**6.2.3**	Non-metallic liner welds			•

6.2 Metallic Cylinders and Liners

6.2.1 *Steel*

Steels for cylinders and liners shall conform to the materials requirements of clauses **5.1** to **5.6** of IS 15490. Stainless steels are not considered for cylinders and liners.

6.2.2 *Aluminium*

Aluminium alloy shall conform to the material requirement of clause **5.1** of IS 15660. Aluminium alloys not covered by above may be used, provided that hydrogen compatibility is demonstrated according to the method specified in **H-2**.

6.2.3 *Non-metallic Liners*

The non-metallic liner material shall be compatible with the service conditions specified in **4**. The liner melt temperature shall be sufficiently high to allow gas release only through pressure relief devices during fire tests (*see* **H-7** for further details).

The tensile yield strength and ultimate elongation shall be determined in accordance with ASTM D638. Tensile or impact testing shall be conducted on samples of the nonmetallic liner material to demonstrate that the material fails in a ductile, rather than brittle, mode at temperatures down to −50 °C.

The softening temperature shall be sufficiently high to meet the service conditions specified in **4**. The cylinder manufacturer shall establish the suitable value for the softening temperature and the testing shall be in accordance with the method described in IS 13360 (Part 6/Sec 1) or using an equivalent method.

6.2.4 *Bosses for Type 4 Cylinders*

Materials shall be compatible with the liner and intended environment and shall meet the requirements of **6.1**, **6.2.1** and **6.2.2** as applicable.

6.3 Resin

The material for impregnation may be thermosetting or thermoplastic resins. Examples of suitable matrix materials are epoxy, modified epoxy, polyester and vinyl ester thermosetting plastics, as well as polyethylene and polyamide thermoplastic. Resin system materials shall be tested on a sample test panel, representative of the composite overwrap, in accordance with ASTM D2344. Following a 24 h water boil, the composite shall have a minimum shear strength of 13.8 MPa.

The glass transition temperature of the resin material shall be at least 20 °C above the maximum cylinder temperature (that is ≥ 105 °C) and shall be determined in accordance with IS 15935.

6.4 Impact Test of Steel

Impact tests for steel cylinders or liners, in accordance with clause **9.3.3** of IS 15490 or as appropriate and meet the requirements therein. Impact test shall be carried out in accordance with IS 1757 (Part 1). All impact tests shall be conducted at −40 °C.

6.5 Tensile Tests for Metals

Tensile strength tests shall be carried out in accordance with IS 15490 for steel, and IS 15660 for aluminium, and shall meet the requirements of the designs.

6.6 Ultraviolet Resistance of External Coating

Protective coatings required to meet **9.2.2.9** shall be evaluated for resistance to ultraviolet effects using a minimum 1 000 h exposure using a UVA 340 lamp in accordance with ASTM G154. Evidence of blistering, cracking, chalking, or softening shall be a cause for rejection.

6.7 Fibre

Structural reinforcing filament material types shall be glass fibre, aramid fibre, or carbon fibre. If carbon fibre reinforcement is used, the design shall incorporate means to prevent galvanic corrosion of metallic components of the cylinder.

The cylinder manufacturer shall keep on file for the intended life of the cylinder design the published specifications for composite materials and the material manufacturer's recommendations for storage conditions and shelf life. The cylinder manufacturer shall keep on file, for the intended life of each batch of cylinders, the fibre manufacturer's certification that each shipment conforms to the manufacturer's specifications for the product.

7 DESIGN REQUIREMENTS

7.1 General

This standard neither provides design formulae nor lists permissible stresses or strains, but requires the adequacy of the design to be established by appropriate calculations and demonstrated by cylinders being capable of consistently passing the materials, design qualification, production and batch tests specified in this standard. However, cylinders manufactured in conformance with IS 15490 and IS 15660 may be used as Type 1 cylinders, or as metal liners for Type 2 and Type 3 cylinders.

During pressurization, this type of cylinder design exhibits behaviour in which the displacements of the composite overwrap and the metal liner are linearly superimposed. Due to different techniques of the manufacture, this standard does not give definite method for design.

The design shall ensure a 'leakage-before-break' failure mode under feasible degradation of pressure parts during normal services. If leakage of the metal liner occurs, it shall be only by the growth of a fatigue crack.

7.2 Test Pressure

The minimum test pressure used during manufacturing shall be 1.5 times the working pressure.

7.3 Burst Pressure and Fibre Stress Ratio

7.3.1 *Cylinder*

The minimum actual burst pressure of the finished cylinder shall not be less than the values given in **9.2.3.3**. 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 given in Table 2.

Stress ratio is defined as the stress in the fibre at the specified minimum burst pressure divided by the stress in the fibre at working pressure.

The burst ratio is defined as the actual burst pressure of the cylinder divided by the working pressure.

Composite reinforcement used on cylinders shall also meet the minimum stress ratio requirements of Table 2. Verification of the stress ratios may be done by calculation. When the calculation method is used, the stress ratio calculations shall include the following:

a) An analysis method with capability for non-linear materials, such as a special purpose computer program or a finite element analysis program;
b) Correct modeling of the elastic-plastic stress-strain curve for the liner material;
c) Correct modeling of the mechanical properties of the composite materials;
d) Calculations at autofrettage pressure, zero pressure after autofrettage, working pressure and minimum burst pressure;
e) Account for the pre-stresses from the winding tension;
f) Minimum burst pressure, chosen such that the calculated stress at minimum burst pressure divided by the calculated stress at the working pressure meets the stress ratio requirements for the fibre used; and
g) When analyzing cylinders with hybrid reinforcement (two or more different fibre), consideration of the load share between the different fibres based on the different elastic moduli of the fibres. The stress ratio requirements for each individual fibre type shall be in accordance with the values given in Table 2. Verification of the stress ratios may also be performed using strain gauges. An acceptable method is provided in Annex C.

7.4 Stress Analysis

A stress analysis shall be performed to justify the minimum design wall thickness. It shall include the determination of the stresses in the liners and fibres of composite designs for a given pattern of winding.

Table 2 Minimum Stress Ratios

(*Clauses* 7.3.1, 9.2.2.5 *and* H-4)

Sl No.	Construction	Minimum Stress Ratio		
		Type 2	**Type 3**	**Type 4**
(1)	(2)	(3)	(4)	(5)
i)	All-metal			
ii)	Glass	2.65	3.5	3.5
iii)	Aramid	2.25	3.0	3.0
iv)	Carbon (working pressures less than 35 MPa)	2.25	2.25	2.25
v)	Carbon (working pressures greater than or equal to 35 MPa)	2.25	2.25	2.25
vi)	Hybrid	[1]	[1]	[1]

[1] Stress ratios shall be calculated in accordance with **7.3.1** (g). The stress ratio requirements for each individual fibre type shall be in accordance with the values given above.

For Type 2, Type 3 and Type 4 design, the stresses in the composite and in the liner after pre-stress shall be calculated at zero pressure, working pressure, test pressure and design burst pressure. The calculations shall use suitable analysis techniques taking account of non-linear material behaviour of the liner to establish the stress distributions.

For Type 2 and Type 3 design using auto-frettage to provide pre-stress, the limits within which the auto-frettage pressure shall fall shall be calculated and specified. For Type 3 design using controlled tension winding to provide pre-stress, the temperature at which it shall be performed, the tension required in each layer of the composite and the consequent pre-stress in the liner shall be calculated.

For Type 2 and Type 3 design, the stresses in the composite shall be calculated in the tangential and longitudinal direction of the cylinder. The pressures used for these calculations shall be zero pressure, working pressure, test pressure, and design burst pressure. The calculations shall use suitable analysis techniques to establish the stress distribution throughout the cylinder.

7.4.1 *External Loads on Cylinders*

Cylinders with greater than 450 litre water capacity and all cylinders employing integral mounts or valve protection shall consider the external loads imposed on the cylinder as a function of the service conditions and mounting provisions. This includes bending and torsional stresses.

7.5 Maximum Defect Size

For Type 1, Type 2 and Type 3 designs, the maximum defect size for non-destructive examinations (NDE) shall be established by a method suitable for the design. This method shall demonstrate that a cylinder with defects of the specified defect size will meet the ambient temperature pressure cycling requirements of **H-5**. The NDE method shall be capable of detecting the maximum defect size allowed.

NOTE — An example of a suitable method for establishing the maximum defect size is given in Annex E.

7.6 Fire Protection

The cylinder design shall be protected with pressure relief devices. The cylinder, its materials, non-reclosing thermally activated pressure relief devices and any added insulation or protective material or non-reclosing pressure-activated pressure relief devices, shall be designed collectively to ensure adequate safety during fire conditions of the test specified in **H-7**. In no case shall a pressure relief device be composed of thermally activating and pressure- activating functions acting in series such that both functions are required to activate to prevent a cylinder from bursting due to fire effects.

Provided that the finished cylinder with its fire protection system has passed the requirements of the bonfire test in **H-7**, alternative installation configurations for the fire protection system can be used if it can be demonstrated to provide the same or an improved level of safety. The final fire protection system used for vehicle installations involving multiple cylinders may require a different arrangement or number of non-reclosing thermally activated pressure relief devices.

This whole clause is deleted because in India each cylinder must have a valve with its associated PRD.

In case of additional PRD to be placed along the length, that is multiple PRDs in parallel for single cylinder each PRD shall be capable of relieving the gas contents and prevent bursting of cylinder during bonfire test.

NOTES

1 The non-reclosing thermally activated pressure relief device that is part of the cylinder manufacturer specified fire protection system is not necessarily provided with the cylinder. It is, however, required that the effectiveness of this fire protection system be demonstrated by subjecting the same to the bonfire test with that cylinder model.

2 It should not be possible to isolate the non-reclosing thermally activated pressure relief device from the cylinder by the operation or failure of another component.

8 CONSTRUCTION AND WORKMANSHIP

8.1 Materials

Type 1 designs shall be of seamless construction using steel that comply with the materials requirements in **6.2**. Type 2 or Type 3 liners shall be constructed from steel or aluminium that comply with the materials requirements in **6.2** or **6.3**, as appropriate.

8.2 Type 3 Metal Liner

For Type 3 designs, the compressive stress in the liner at zero pressure and the design temperature range shall not cause the liner to buckle or crease.

For Type 3 liners subjected to cold-forming or cryo-forming processes, heat treatment of the pre-form component is not required. Liners that have been cold-formed or cryo-formed shall not be subjected to any subsequent heat treatment or to additional heat application, such as welding.

NOTE — During pressurization, a Type 3 design has a behaviour in which the displacements of the composite over-wrap and the metal liner are linearly superimposed.

Due to different manufacturing techniques, this standard does not give a definite method for design.

8.3 Neck Threads

The cylinder neck shall be threaded to suit the type of valves as given in IS 3224 or any other specification as approved by the statutory authority. The threads shall be full form, clean cut, even and without surface discontinuities, to gauge, and concentric with the axis of the cylinder.

8.4 Forming

For Type 1 cylinders and liners, a forming process such as gas/arc welding shall not be used to fully close and seal the ends. The base ends of Type 1 steel cylinders that have been closed by forming shall be inspected using NDE, methods in clause **7.2** of IS 15490 or other equivalent techniques). Metal shall not be added in the process of closure at the end. Each cylinder shall be examined before end forming operations for thickness and surface finish.

After end forming, the cylinders shall be heat treated to the hardness range specified for the design. Localized heat treatment shall not be used.

8.5 Fibre Winding

Type 2, Type 3, and Type 4 cylinders shall be fabricated from a liner over-wrapped with continuous filament windings. Fibre winding operations shall be computer controlled. The fibre shall be applied under controlled tension during winding.

During winding, the significant variables shall be monitored to demonstrate that they remain within specified tolerances. The results shall be documented in a winding record that shall be retained by the cylinder manufacturer for the intended life of each batch of cylinders. These variables can include but are not limited to the following:

a) Fibre type, including sizing;
b) Manner of impregnation;
c) Winding tension;
d) Winding speed;
e) Number of rovings;
f) Band width;
g) Type of resin and composition;
h) Temperature of the resin;

j) Temperature of the liner;
k) Winding angle; and
m) Winding program reference number.

8.6 Curing of Thermosetting Resins

If a thermosetting resin is used, the resin shall be cured after the fibre winding is complete. Thermosetting resins shall be cured by heating, using a predetermined and controlled time-temperature profile. During the curing, the curing cycle (that is the time-temperature history) shall be documented and retained by the cylinder manufacturer for the intended life of each batch of cylinders.

The maximum curing time and temperature for cylinders with aluminium alloy liners shall not adversely affect metal, resin, and fibre properties.

8.7 Autofrettage

Autofrettage, if used, shall be carried out before the hydraulic test specified in **10.2** (c). The autofrettage pressure shall be within the limits established in **7.4**. The cylinder manufacturer shall establish the method to verify that the appropriate pressure is applied. Records of autofrettage pressure shall be retained by the cylinder manufacturer for the intended life of each batch of cylinders.

8.8 Exterior Environmental Protection

Exterior protection may be provided by using any one of the following:

a) A surface finishes giving adequate protection (for example, metal sprayed on aluminum, anodizing);
b) A suitable fibre and matrix material (for example, carbon fibre in resin); and
c) A protective coating (for example, organic coating, paint).

If a protective coating is part of the design, the coatings shall be evaluated using the test methods in **H-1**.

Any coatings applied to cylinders shall be such that neither the coating nor the application process adversely affects the mechanical properties of the cylinder. The coating shall be designed to facilitate subsequent in-service inspection, and the manufacturer shall provide guidance on coating treatment during such inspection to ensure the continued integrity of the cylinder.

9 TYPE APPROVAL PROCEDURE

9.1 Qualification of New Designs

A technical specification of each new design of cylinder including design drawing, design calculations, material details and heal treatment, shall be submitted by the manufacturer to the statutory authority, through or vetted by the inspection agency. The test detailed in **9.2** shall be carried out on each new design under the supervision of the inspector.

The cylinder manufacturer shall retain the prototype test results for the intended service life of the cylinder design. The test data shall also document the dimensions, wall thickness and weights of each of the tested cylinder.

9.2 Prototype Tests

9.2.1 *General Requirement*

A minimum of 50 cylinders or liners which are guaranteed by the manufacturer to be representative of the new design shall be made available for prototype testing. However, if for special applications the total number of cylinders or liners required is less than 50, enough cylinders or liners shall be made to complete the prototype tests required, in addition to the production quantity. All cylinders subjected to prototype tests shall be made unserviceable after the tests.

In the course of the type approval process, the inspector shall select the necessary cylinders or liners for testing and supervise the following tests on the cylinders or liners selected.

Unless otherwise permitted by **9.3**, Cylinders representative of each design and design change shall successfully meet the requirements of a Category A, Category B, or Category C design qualification test.

Category A design qualification requirements are prescribed in Table 3, using procedures found in **9.2.2**.

Category B design qualification requirements are prescribed in Table 4, using procedures found in **9.2.2** and **9.2.3**.

Category C design qualification requirements are prescribed in Table 3, using procedures found in **9.2.2** and with the conditions and limitations found in **9.2.4**.

Table 3 Summary of Prototype Tests for Category A and Category C Cylinders
(*Clause* 9.2.1)

Sl No.	Type of Test	Number of Cylinders Required for Testing	For Type 1	For Type 2	For Type 3	For Type 4
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	Material tests for steel cylinders and liners (*see* **9.2.2.2**)	1 cylinder or liner	√	√	√	
ii)	Material tests for aluminium alloy fuel tanks and liners (*see* **9.2.2.3**)	1 liner	√	√	√	
iii)	Resin properties (*see* **9.2.2.4**)	composite samples		√	√	√

iv)	Hydrostatic burst (*see* **9.2.2.5**)	3 plus 1 liner	√	√	√	√
v)	Ambient temperature pressure cycling (*see* **9.2.2.6**)	3	√	√	√	√
vi)	Leak-before-break (LBB) (*see* **9.2.2.7**)	3	√	√		
vii)	Bonfire (*see* **9.2.2.8**)	1 or 2	√	√	√	√
viii)	Chemical exposure (*see* **9.2.2.9**)	1		√	√	√
ix)	Flaw tolerance (*see* **9.2.2.10**)	1		√	√	√
x)	Accelerated stress rupture (*see* **9.2.2.11**)	1		√	√	√
xi)	Extreme temperature pressure cycling (*see* **9.2.2.12**)	1		√	√	√
xii)	Drop (*see* **9.2.2.13**)	1		√	√	√
xiii)	Hydrogen gas cycling (*see* **9.2.2.14**)	1	√	√	√	√
xiv)	Permeation (*see* **9.2.2.15**)	1				√
xv)	Boss torque (*see* **9.2.2.16**)	1				√
xvi)	High strain rate impact (*see* **9.2.2.17**)	1	√	√	√	√

NOTE — '√' indicates that the test to be performed.

Table 4 Test requirements for Category B cylinders

(*Clause* 9.2.1)

Sl No. (1)	**Clause** (2)	**Type of Test** (3)
i)	9.2.3.2	Ambient temperature pressure cycling test (*see* **9.2.2.6**)
ii)	9.2.3.3	Hydrostatic burst test (*see* **9.2.2.5**)
iii)	9.2.3.4	Cylinder test for performance durability
iv)	9.2.2.8	Bonfire test
v)	9.2.3.5	Cylinder test for expected on-road performance

9.2.2 *Category A, B and C: Design Qualification Tests*

9.2.2.1 *Test requirements*

Category A and C cylinders shall be subjected to the tests specified in **9.2.2**. Category B cylinders shall be subjected to the tests specified in **9.2.2**, as applicable.

9.2.2.2 *Material tests for steel cylinders and liners*

If the cylinder or liner is made of steel, appropriate material tests in accordance with clause **9.3** of IS 15490 shall be carried out on one liner. The tensile strength shall meet the manufacturer's design specifications. For Type 1 design, the steel elongation shall be at least 14 percent. For Type 3 designs, the tensile strength and elongation shall meet the manufacturer's design specifications.

The hydrogen compatibility of steels in contact with hydrogen shall be demonstrated in accordance with **B-2**. Steels that conform to clauses **5.3** and **5.5** of IS 15490 are exempted from this test.

9.2.2.3 *Material tests for aluminium alloy fuel tanks and liners*

For Type 1 fuel tanks, **10.2** and **10.3**, as well as Annex G and Annex H shall be carried out on one cylinder or liner. The materials properties shall meet the manufacturer's design specifications.

For Type 3 liners using aluminium alloy, materials tests as required in IS 15660 and Annex H shall be carried out on one liner. The materials properties, including elongation, shall meet the manufacturer's design specifications as well as Annex G and Annex H.

The hydrogen compatibility of aluminium alloys in contact with hydrogen shall be demonstrated in accordance with **B-2**. Aluminium alloys that conform to clauses **6.1** and **6.2** of IS 15660 are exempted from this test.

9.2.2.4 *Resin properties tests*

For Type 3 designs, samples representative of the composite over-wrap shall be tested in accordance with **H-3**. Resin materials shall meet the requirements therein.

9.2.2.5 *Hydrostatic burst test*

For all designs, three cylinders shall be hydrostatically pressurized to failure in accordance with **H-4**. For each cylinder, the burst pressure shall exceed the minimum burst pressure given in **9.2.3.3**. In no case shall the burst pressure be less than the value necessary to meet the stress ratio requirements in Table 2. The average of the burst pressure results of the three cylinders shall be recorded for future reference.

9.2.2.6 *Ambient temperature pressure cycling test*

For all designs, two cylinders shall be pressure cycled at ambient temperature in accordance with **H-5** and meet the requirements therein.

9.2.2.7 *Leak-Before-Break (LBB) test*

For all designs, three cylinders shall be tested in accordance with **H-6** and shall meet the requirements therein.

9.2.2.8 *Bonfire test*

For all designs, one or two cylinders as appropriate shall be tested in accordance with **H-7** and meet the requirements therein.

9.2.2.9 *Chemical exposure test*

For Type 2, Type 3 and Type 4 designs, one cylinder shall be tested in accordance with **H-8** and meet the requirements therein.

9.2.2.10 *Flaw tolerance test*

For Type 2, Type 3 and Type 4 designs, one cylinder shall be tested in accordance with **H-9** and meet the requirements therein.

9.2.2.11 *Accelerated stress rupture test*

For Type 2, Type 3 and Type 4 designs, one cylinder shall be tested in accordance with **H-10** and meet the requirements therein.

9.2.2.12 *Extreme temperature pressure cycling test*

For Type 2, Type 3 and Type 4 designs, one cylinder shall be tested in accordance with **H-11** and meet the requirements therein.

9.2.2.13 *Drop test*

For Type 2, Type 3 and Type 4 designs, one or more finished cylinders shall be tested in accordance with **H-12** and meet the requirements therein.

9.2.2.14 *Hydrogen gas cycling test*

For all designs, one finished cylinder shall be tested in accordance with **H-13** and meet the requirements therein.

9.2.2.15 *Permeation test*

For all designs, one finished cylinder shall be tested in accordance with **H-18** and meet the requirements therein.

9.2.2.16 *Boss torque test*

For Type 4 design, one finished cylinder shall be tested in accordance with **H-19** and meet the requirements therein.

9.2.2.17 *High strain rate impact test*

For all designs, one finished cylinder shall be tested in accordance with **H-20** and meet the requirements therein.

9.2.3 *Category B: Design Qualification Tests*

9.2.3.1 *General test requirements*

Category B cylinders shall be subjected to the tests specified in **9.2.3**.

Cylinders subjected to these tests are intended to be integrated into a compressed hydrogen storage system, including all closure devices (such as shut-off valves, check valves, pressure relief devices, etc.) and piping, and are expected to meet the additional test requirements [Verification Test for Expected On-Road Performance (Sequential Pneumatic Tests), Verification Test for Service Terminating Performance in Fire in the UN GTR No. 13 or SAE J2579].

9.2.3.2 *Ambient temperature pressure cycling test*

Cylinders shall be subjected to the pressure cycling test specified in **9.2.2.6**.

9.2.3.3 *Hydrostatic burst test*

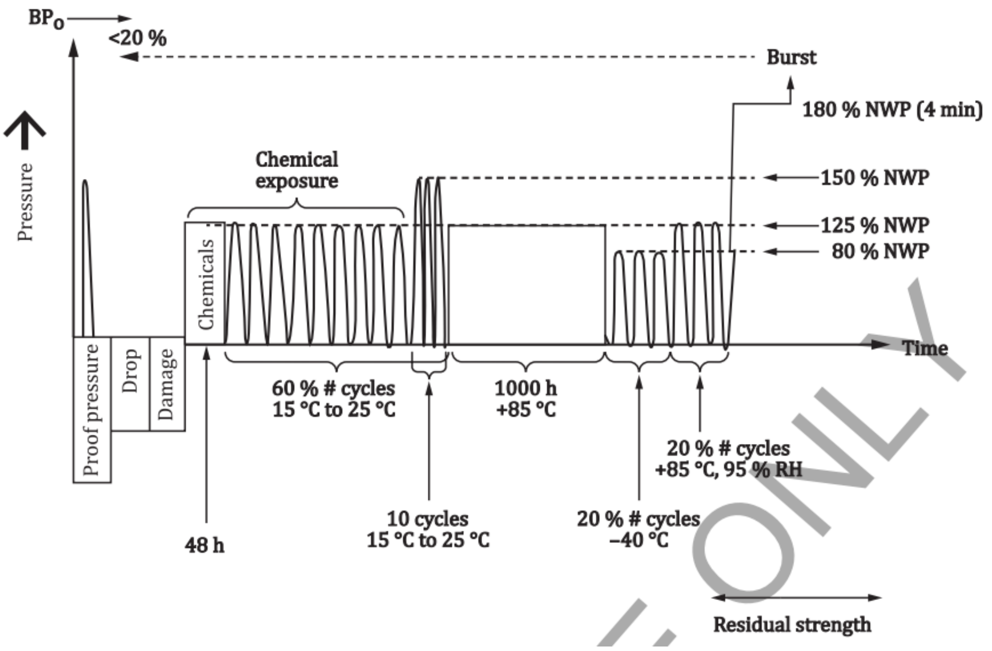
Cylinders shall be subjected to the burst test specified in **9.2.2.5**. The cylinder manufacturer shall supply documentation (measurements and statistical analyses) that establishes the midpoint burst pressure of new cylinders.

All cylinders tested shall have a burst pressure within ±10 percent of the midpoint and greater than 225 percent of the nominal working pressure and in no case less than the value necessary to meet the burst/nominal working pressure ratio requirement of **7.3,** for Type 1 cylinders, or the stress ratio requirement of **7.4**, when analysed in accordance with the requirements of **7.4**. The actual burst pressure shall be recorded.

9.2.3.4 *Cylinder test for performance durability*

9.2.3.4.1 *Test requirements*

If all three pressure cycle life measurements determined per **9.2.3.2** are greater than 11 000 cycles or if they are all within ±25 percent of each other, only one cylinder shall be subjected to the tests specified in **9.2.3.4**. Otherwise, three cylinders shall be tested. The cylinder(s) shall not leak during the following sequence of tests, which are applied in series to an individual cylinder(s) and which are illustrated in Fig. 1.



NOTE — BP_O is the midpoint burst pressure of new cylinders.

FIG. 1 VERIFICATION TEST FOR PERFORMANCE DURABILITY

9.2.3.4.2 *Proof pressure test*

Cylinders shall be subjected to the proof pressure test specified in **H-15** (b). If a cylinder has previously undergone a proof pressure test in manufacture, then the cylinder shall be exempt from this test.

9.2.3.4.3 *Drop test*

Cylinders shall be subjected to the drop test conditioning specified in **9.2.2.13**.

9.2.3.4.4 *Surface damage test*

Cylinders shall be subjected to the surface flaw conditioning specified in **H-9.1** (a) or **H-9.1** (b), except that the flaws shall be introduced in the bottom surface of the cylinder and the 25 mm long cut shall be situated toward the valve end of the cylinder and the 200 mm long cut shall be situated opposite the valve end of the cylinder.

The upper surface of the cylinder shall be subjected to the pendulum impact conditioning specified in **H-8.1**, except that the cylinder shall be preconditioned at −40 °C for 12 h prior to the pendulum impacts.

9.2.3.4.5 *Chemical exposure and ambient pressure cycling*

Cylinders shall be subjected to the chemical conditioning specified in **9.2.2.9**, except that the cylinder shall be held at the ambient temperature and 125 percent of the nominal working pressure (±1 MPa) for 48 h before the cylinder is subjected to further testing.

Cylinders shall be subjected to the pressure cycling test specified in **9.2.2.6** to 60 percent of 5 500, 7 500 or 11 000 cycles, as appropriate. Chemical exposure shall be discontinued by removing the glass wool pads and rinsing the cylinder surface with water before the last 10 cycles, which shall be conducted to 150 percent of the nominal working pressure (±1 MPa).

9.2.3.4.6 *High temperature static pressure test*

Cylinders shall be pressurized to 125 percent of the nominal working pressure (±1 MPa) while at a temperature of 85 °C. The cylinder shall be held at this pressure and temperature for 1 000 h.

9.2.3.4.7 *Extreme temperature pressure cycling test*

Cylinders shall be pressure cycled at −40 °C or lower to 80 percent of the nominal working pressure (±1 MPa) in accordance with the test procedure specified in **H-11** (c), (d) and (e), except that the cylinder shall be cycled to 20 percent of 5 500, 7 500 or 11 000 cycles, as appropriate.

Cylinders shall be pressure cycled at 85 °C or higher to 125 percent of the nominal working pressure (±1 MPa) in accordance with the test procedure specified in **H-11** (a) and (b), except that the cylinder shall be cycled at 95 percent relative humidity and to 20 percent of 5 500, 7 500 or 11 000 cycles, as appropriate.

9.2.3.4.8 *Hydraulic residual pressure test*

Cylinders shall be pressurized to 180 percent of the nominal working pressure and held for 4 min. The cylinder shall not rupture.

9.2.3.4.9 *Residual burst test*

Cylinders shall be subjected to the burst test specified in **9.2.2.5**. The cylinder shall burst at a pressure that is at least 80 percent of the burst pressure determined in **9.2.2.5**.

9.2.3.5 *Cylinder test for expected on-road performance*

In order for a Category B cylinder to be fully qualified for on-road vehicle usage, a cylinder test shall be conducted at a system level in accordance with the UN GTR No. 13, SAE J2579 or equivalent hydrogen and fuel cell vehicle standards.

9.2.4 *Category C: Design Qualification Conditions and Limitations*

9.2.4.1 *Markings*

Clause **11.1** (g) does not apply.

9.2.4.2 *Material tests for steel cylinders and liners*

If the cylinder or liner is made of steel, appropriate material tests in accordance with clauses **10.2** to **10.4** of IS 7285 (Part 2), shall be carried out on one liner. The tensile strength shall meet the cylinder manufacturer’s design specifications. For Type 1 and Type 2 cylinders the steel elongation shall be at least 14 percent. For Type 3 cylinders the tensile strength and elongation shall meet the cylinder manufacturer's design specifications.

9.2.4.3 *Material tests for aluminum alloy cylinders and liners*

For Type 1 cylinders and Type 2 liners using aluminum alloy, appropriate material tests as required in clauses **9.2** and **9.3** of IS 15660, as well as Annex A and Annex B, shall be carried out on one cylinder or liner. The materials properties shall meet the cylinder manufacturer's design specifications. The elongation shall be at least 12 percent. For Type 3 liners using aluminum alloy, materials tests as required in clause **10.2** of IS 15660 and Annex D of IS 15660 shall be carried out on one liner. The materials properties, including elongation, shall meet the cylinder manufacturer's design specifications.

A suitable aluminium alloy for hydrogen service is AA6061 in the T6, T62, T651 or T6511 heat treats.

9.3 Exemptions to Type Tests

As an alternative to the requirements in **9.2**, Type 1 steel design meeting the requirements of IS 15490 and the additional requirements specified in **7.6** and **8.8** may only be subjected to the bonfire test in **9.2.2.8** and the hydrogen compatibility tests in **H-2**.

As an alternative to the requirements in **9.2**, Type 1 aluminium alloy design meeting the requirements of IS 15660 and the additional requirements specified in **7.6** and **8.8** may only be subjected to the bonfire test in **9.2.2.8** and the hydrogen compatibility tests in **H-2**.

9.4 Prototype Tests for Design Changes

A cylinder shall be considered to be a new design, compared with an existing approved design, when:

a) It is manufactured in a different factory;
b) It is manufactured by a different process;
c) It is manufactured from a steel of different specified chemical composition;
d) It is given a different heat treatment beyond the stipulated limit;
e) Ends or ends profile has changed for example convex, hemispherical, torispherical, ellipsoidal or also, if there is a change in base thickness to cylinder diameter ratio;
f) Overall length of the cylinder has changed more than 50 percent (cylinders with a length-diameter ratio less than three shall not be used as reference cylinders for any new design with this ratio greater than three);
g) Nominal outside diameter has changed more than 5 percent;
h) Hydraulic test pressure has been increased (where a cylinder is to be used for lower pressure duty than that for which design approval has been given, it shall not be deemed to be a new design;
j) It is manufactured using a different fibre;
k) It is manufactured using a different resin; and
m) The winding pattern is changed.

The cylinder material, design, manufacturing process and examination shall be proved to be adequate for their intended service by meeting the requirements of the prototype tests specified in **9.2** for generic automotive vehicle use.

Design changes may be qualified through a reduced test program as given in Table 5. Design changes that exceed the changes defined in Table 5 shall be qualified by a complete test program.

A fibre shall be considered to be of a new fibre type when any of the following conditions apply:

a) The fibre is of a different classification, for example, glass, aramid, carbon;
b) The fibre is produced from a different precursor (starting material), for example, Polyacrylonitrile (PAN), pitch for carbon;
c) The nominal fibre modulus specified by the fibre manufacturer differs by more than ±5 percent from that defined in the prototype-tested design; and
d) The nominal fibre strength specified by the fibre manufacturer differs by more than ±5 percent from that defined in the prototype-tested design.

A resin material shall be considered to be a new resin type when any of the following conditions apply:

a) The resin is of a different specification for example, thermosetting or thermoplastic.

Second design change approval with a reduced set of tests (that is, multiple changes from an approved design are not permitted). If a test has been conducted on a design change (*X*) that falls within the testing requirements for a second design change (*Y*), then the result for (*X*) can be applied to the new design change (*Y*) test program. However, design change (*X*) cannot be used as the reference for determining the testing required for any new design change.

Table 5 Prototype Tests for Design Changes
(*Clause* 9.4)

Sl No.	**Clause No.**	**Test**	**Design Change**														
			Fibre Manufacturer	Materials			Length		Diameter[1)]		Working Pressure[1)] < 20 Percent	Dome shape	Opening size	Coating	Fire protection system[2)]	Manufacturer[3)]	Boss Material or Geometry
				Fibre	Resin	Metal Cylinder or Liner	≤ 50 Percent	> 50 Percent	≤ 20 Percent	> 20 Percent							
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
i)	**9.2.2.5**	Hydrostatic burst	X	X		X	X	X	X	X		X	X			X	X[4]
ii)	**9.2.2.6**	Ambient temperature pressure cycling	X	X		X		X	X	X		X	X			X	X[4]
iii)	**9.2.2.7**	LBB	X	X													
iv)	**9.2.2.8**	Bonfire		X		X	X[a]	X[a]		X	X				X		
v)	**9.2.2.9**	Chemical exposure		X	X	X*											
vi)	**9.2.2.10**	Flaw tolerance		X	X	X*				X				X			
vii)	**9.2.2.11**	Accelerated stress rupture	X	X	X	X*											
viii)	**9.2.2.13**	Drop	X	X	X	X*		X	X	X							
ix)	**H-2** **9.2.2.14**	Hydrogen compatibility or Hydrogen gas cycling				X											
x)	**9.2.2.15**	Permeation				X											X[5]
xi)	**9.2.2.16**	Boss torque													X[6]		X

xii)	**9.2.2.17**	High strain rate impact	X	X	X[7]	X[8]	X[9]		X[10]	X							

X indicates test is applicable.

***** indicates test not required for Type 1 cylinders.

X [a] indicates test only when length increases.

1) Only when thickness changes proportional to diameter and/or pressure change, otherwise qualify as a new design.

2) Change in fire protection system, non-reclosing thermally activated pressure relief device or location of non-reclosing thermally activated pressure relief device.

3) Any deviation from the manufacturing parameters specified in **5.2.7** is a change in the manufacturing process. Test not required on Type 1 metal cylinders.

4) Only one unit required for design change, may be done as part of batch test.

5) Geometry only.

6) Only applicable for an increase in the valve torque.

7) Test not required when resin of the same chemical and physical properties are substituted.

8) Test not required for Type 4 cylinders.

9) Test only required when the resulting cylinder sidewall is less than the diameter.

10) Test required only if the diameter decreases.

10 BATCH TESTS AND TESTS ON EVERY CYLINDER

10.1 Batch Tests

10.1.1 *General Requirements*

Batch tests shall be carried out on each batch of cylinders or liners.

Batch tests shall be conducted on finished liners and cylinders that are representative of normal production, complete with identification marks. The cylinders and liners required for testing shall be randomly selected from each batch. If more cylinders are subjected to the tests than are required, all results shall be documented.

Batches of cylinders shall be proved to be adequate for their intended service by meeting the requirements of the batch tests specified in **10.1.2**. The cylinder manufacturer shall retain the batch test results and relevant data for each batch (for example cast number) for the intended life of the cylinders in the batch. All cylinders subjected to batch tests shall be made unserviceable after the tests.

10.1.2 *Required Tests*

One cylinder shall be subjected to the hydrostatic burst pressure test in accordance with **H-4**. The cylinder burst pressure shall exceed the specified minimum shall exceed the minimum burst pressure requirement given in **7.3** and stress ratio requirement given in **9.2.3.3**.

One cylinder shall be subjected to pressure cycle testing in accordance with the requirements in **10.1.3**. The cylinder used for the pressure cycle test in **10.1.3** may also be used for the burst pressure test. If the burst pressure of the cycled cylinder is less than the minimum required burst pressure, an additional burst test shall be conducted on a cylinder from batch.

For Type 1, Type 2, and Type 3 designs, a further cylinder, liner or sample representative of a finished cylinder or liner shall be subjected to the following tests.

a) Verification of the critical dimensions of the design;
b) Tensile tests for steel cylinders or liners, in accordance with clause **9.3.1** of IS 15490 or tensile tests for aluminum alloy cylinders or liners, in accordance with clause **9.2** of IS 15660. The tensile test shall be carried out in accordance with IS 1608. The test results shall satisfy the requirements of the design;
c) Impact tests for steel cylinders or liners, in accordance with clause **9.3.3** of IS 15490 or as appropriate and meet the requirements therein. Impact test shall be carried out in accordance with IS 1757 (Part 1); and
d) When a protective coating according to **8.8** is a part of the design, a coating batch test shall be performed in accordance with **H-18**. Where the coating fails to meet the requirements of **H-18**, the batch shall be 100 percent inspected to remove similarly defectively coated cylinders. The coating on all defectively coated cylinders shall be stripped using a method that does not affect the integrity of the composite wrapping and recoated. The coating batch test shall then be repeated. All cylinders and liners represented by a batch test that fails to meet the requirements specified shall follow the procedures specified in **10.3**.

10.1.3 *Ambient Temperature Pressure Cycling Test*

The following test shall be carried out on finished cylinders at a test frequency defined as follows:

Initially, one cylinder from each batch shall be pressure cycled from not more than 2 MPa to not less than 1.25 times the working pressure at a rate not to exceed 10 cycles per min for the number of filling cycles specified in **4.4**.

10.2 Test on Every Cylinder

Production verifications and tests shall be carried out as follows on all cylinders produced in a batch. Non-destructive examinations shall be carried out in accordance with a standard acceptable to the inspector.

Each cylinder shall be examined during manufacture and after completion as follows:

a) By NDE of metallic cylinders and liners in accordance with Annex B of IS 15490 to confirm that the maximum defect size does not exceed the specified in the design as determined in accordance with **7.5**. The NDE method shall be capable of detecting the maximum defect size allowed;
b) Hardness tests or equivalent tests of metallic cylinders and liners in accordance with **H-14** carried out after the final heat treatment. The values thus determined shall be in the range specified for the design;
c) Hydraulic test of finished cylinders in accordance with **H-15**. For Type 1 and Type 3 designs, the permanent volumetric expansion shall not exceed the limit of permanent volumetric expansion specified by the cylinder manufacturer for the test pressure used. In addition, in no case shall the permanent expansion exceed 10 percent of the total volumetric expansion measured under the test pressure;
d) To verify that critical dimensions and mass of the completed cylinders and of the liners and over wrapping are within design tolerances;
e) To verify compliance with specified surface finish with special attention to deep drawn surfaces and folds or laps in the neck or shoulder of forged or spun end enclosures or openings; and
f) To verify the markings.

10.3 Failure to Meet Test Requirements

In the event of failure to meet test requirements, re-testing or re-heat treatment and re-testing shall be carried out as follows:

a) If there is evidence of a fault or an error of measurement in carrying out a test, a further test of the same kind shall be performed. If the result of this test is satisfactory, the first test shall be ignored;
b) If the test has been carried out in a satisfactory manner, the cause of test failure shall be identified;
    1) If the failure is considered to be due to the applied heat treatment, the manufacturer may subject all the metal cylinders or liners implicated by the failure to a further heat treatment, that is if the failure is in batch test, the test failure shall require re-heat treatment of all the represented metal cylinders or liners prior to re-testing; However, if the failure occurs sporadically in a production test, then only those metal cylinders or liners which fail

the test shall require re-heat treatment and re-testing;

2) Only the appropriate batch tests needed to prove the acceptability of the new batch shall be performed again. If one or more tests prove unsatisfactory, all metal cylinders or liners of the batch shall be rejected; and
3) If the failure is due to a cause other than the heat treatment applied, all defective metal cylinders or liners shall be either rejected or repaired. Repaired metal cylinders or liners that pass the test(s) required for the repair shall be treated as a separate new batch.

11 MARKINGS

11.1 On each cylinder, the manufacturer shall provide clear, permanent markings not less than 6 mm high.

Marking shall be made either by labels incorporated into resin coatings, labels attached by adhesive, low stress stamps used on the thickened ends of Type 1 designs or any combination of the above. Multiple labels are allowed and should be located such that they are not obscured by mounting rackets. Multiple labels may be used and should be located such that they are not obscured by mounting brackets.

Each cylinder shall be permanently marked with the following information.

a) 'H_2 AND H_2 BLENDS ONLY';
b) 'DO NOT USE AFTER XX/XXXX', where XX/XXXX identifies the month and the year of expiry. The period between the dispatch date and the expiry date shall not exceed the specified service life. The expiry date may be applied to the cylinder at the time of dispatch, provided that the cylinder have been stored in a dry location without internal pressure;
c) Manufacturer's identification;
d) Cylinder identification (a serial number unique for every cylinder);
e) Working pressure (MPa) at temperature (°C);
f) Reference to this Indian Standard, 'IS 16735 : XXXX', along with cylinder type and statutory authority's approval numbers;
g) The words 'USE ONLY MANUFACTURER-APPROVED PRESSURE RELIEF DEVICE';
h) Month and year of hydrostatic test such as MM/YYYY (month in two digits and year in four digits);
j) Water capacity (litre);
k) Periodical retesting on xx – xx – xxxx;
m) If labels are used, there is an additional requirement for a unique identification number and the manufacturer's identification to be permanently marked on an exposed metal surface in order to permit tracing in the event that the label is destroyed; and
n) If the cylinder has a reduced number of filling cycles according to **4.4**, and qualified according to **9.2**, then the cylinder shall additionally be marked 'USE ONLY WITH TAMPER-PROOF FILLING CYCLE COUNTER SYSTEM'.

The expiry date may be applied to the cylinders at the time of dispatch, provided that the cylinders have been stored in a dry location without internal pressure. The period between the dispatch date and the expiry date shall not exceed the specified service life. For Type 3 cylinders the label shall be permanently attached to the cylinder.

The markings shall be placed in the listed sequence, but the specific arrangement may be varied to match the space available. The following is an acceptable example.

a) H_2 AND H_2 BLENDS ONLY;

b) DO NOT USE AFTER XX /XXXX;

c) Manufacturer/Cylinder identifications XXX.X l;

d) IS xxxxx : 20xx, Type x;

e) USE ONLY MANUFACTURER-APPROVED PRESSURE RELIEF DEVICE;

f) Manufacture date 03/2005; and

g) 20 MPa/15 °C.

WARNING — Vehicles with HCNG-4 cylinder shall not be parked in enclosed space for extended periods of time. Leakage between the end connections and the liner shall be considered in the design.

11.2 BIS CERTIFICATION MARKING

Each cylinder may also be marked with the standard mark.

11.2.1 The product(s) conforming to the requirements of this standard may be certified as per the conformity assessment schemes under the provisions of the *Bureau of Indian Standards Act*, 2016 and the Rules and Regulations framed thereunder, and the product(s) may be marked with the Standard Mark.

12 PREPARATION FOR DISPATCH

12.1 Preparation of Dispatch from the Manufacturer's Shop

Every cylinder shall be internally cleaned and dried. Cylinders which are not immediately closed by the fitting of a valve and safety devices, if applicable, shall have plugs, which will prevent entry of moisture and protect threads, fitted to all openings.

The manufacturer's statement of service and all necessary information and instructions to ensure the proper handling, use and in-service inspection of the cylinder shall be supplied to the purchaser. The statement of service shall be accordance with **5.2.3**.

ANNEX A

(*Clause* 2)

LIST OF INDIAN STANDARDS

IS No./Other Standards	*Title*
IS 101	Methods of sampling and test of paints, varnishes and related products
(Part 3/Sec 2) : 1989	Test on paint film Formation: Sec 2 Film thickness
(Part 5/Sec 2) : 1988	Mechanical tests: Sec 2 Flexibility and adhesion (*third revision*)
(Part 8/Sec 2) : 1990	Test for pigments and other solids: Sec 2 Pigments and non-volatile matter (*third revision*)
IS 1500 (Part 1) : 2019/ ISO 6506-1 : 2014	Metallic materials — Brinell hardness test: Part 1 Test method (*fifth revision*)
IS 1608	Metallic materials — Tensile testing
(Part 1) : 2022/ ISO 6892-1 : 2019	Method of test at room temperature (*fifth revision*)
(Part 2) : 2020/ ISO 6892-2 : 2018	Method of test at elevated temperature (*fourth revision*)
(Part 3) : 2018/ ISO 6892-3 : 2015	Method of test at low temperature
IS 1757 (Part 1) : 2020/ ISO 148-1 : 2016	Metallic materials — Charpy pendulum impact test: Part 1 Test method (*fourth revision*)
IS 3224 : 2021	Valve for compressed gas cylinders excluding liquefied petroleum gas (LPG) cylinders — Specification (*fourth revision*)
IS 7241 : 1981	Glossary of terms used in gas technology (*first revision*)
IS 7285 (Part 2) : 2017	Refillable seamless steel gas cylinders — Specification: Part 2 Quenched and tempered steel cylinders with tensile strength less than 1 100 MPa (112 Kgf/mm²) (*fourth revision*)
IS/ISO 11114-4 : 2017	Transportable gas cylinders — Compatibility of cylinder and valve materials with gas contents: Part 4 Test methods for selecting steels resistant to hydrogen embrittlement (*first revision*)
IS 15490 : 2017	Seamless steel cylinders for on-board storage of compressed natural gas as a fuel for automotive vehicles — Specification (*first revision*)
IS 15935 : 2021	Composite cylinders for on-board storage of compressed natural gas (CNG) as a fuel for automotive vehicle — Specification (*first revision*)
IS 15660 : 2017	Refillable transportable seamless aluminium alloy gas cylinders — Specification (*first revision*)
IS 15643 : 2006	Non-destructive examination of polymer based composite materials — Code of practice
IS 16061 : 2021	Hydrogen fuel quality — Product specification (*first revision*)
IS 13360 (Part 6/Sec 1) : 2018/ ISO 306 : 2013	Plastics — Methods of testing: Part 6 Thermal properties section 1 determination of vicat softening temperature of thermoplastic materials (*second revision*)
ASTM D 638 : 2022	Standard test method for tensile properties of plastics
ASTM D 2344 : 2022	Standard test method for short-beam strength of polymer matrix

	composite materials and their laminates
ASTM D4814 : 2022	Standard specification for automotive spark-ignition engine fuel
ASTM G 154 : 2023	Standard practice for operating fluorescent ultraviolet (UV) lamp apparatus for exposure of materials
ISO 1519 : 2011	Paints and varnishes — Bend test (cylindrical mandrel)
ISO 2409 : 2020	Paints and varnishes — Cross-cut test
ISO 4624 : 2023	Paints and varnishes — Pull-off test for adhesion
ISO 4892-1 : 2016	Plastics — Methods of exposure to laboratory light sources — Part 1: General guidance
ISO 9227 : 2022	Corrosion tests in artificial atmospheres — Salt spray tests
ISO 6272 (Part 2) : 2011	Paints and varnishes — Rapid-deformation (impact resistance) tests — Part 2: Falling-weight test, small-area indenter
ISO 9809-1 : 2019	Gas cylinders — Design, construction and testing of refillable seamless steel gas cylinders and tubes — Part 1: Quenched and tempered steel cylinders and tubes with tensile strength less than 1 100 MPa
ISO 9809-2 : 2019	Gas cylinders — Design, construction and testing of refillable seamless steel gas cylinders and tubes — Part 2: Quenched and tempered steel cylinders and tubes with tensile strength greater than or equal to 1 100 MPa

ANNEX B

(*Clause* 4.1)

CYLINDERS INVOLVED IN COLLISION OR FIRE

B-1 CYLINDERS INVOLVED IN COLLISIONS

Cylinders which have been involved in vehicle collision should be re-inspected by the manufacturer. Cylinders which have not experienced any impact damage from the collision may be returned to service, otherwise the cylinder should be returned to the manufacturer for evaluation.

B-2 CYLINDERS INVOLVED IN FIRES

Cylinders which have been subject to the action of fire should be re-inspected by the manufacturer or condemned and removed from service.

B-3 Periodic inspection of cylinders shall be done as per the requirements of statutory authority.

ANNEX C

[*Clauses* 4.2, 5.2.4.2 *and* 7.3.1 (g)]

VERIFICATION OF STRESS RATIOS USING STRAIN GAUGES

C-1 The following describes a procedure that may be used to verify stress ratios by using strain gauges:

a) Stress-strain relationship for fibre is always elastic; therefore, stress ratios and strain ratios are equal;

b) High elongation strain gauges are required;

c) Strain gauges should be oriented in the direction of the fibres on which they are mounted (that is with hoop fibre on the outside of the cylinder, mount gauges in the hoop direction);

d) Method 1 (applies to cylinders that do not use high tension winding);

1) Prior to autofrettage, apply strain gauges and calibrate;
2) Measure strains at autofrettage pressure, zero pressure after autofrettage, working pressure and minimum burst pressure; and
3) Confirm that the strain at minimum burst pressure divided by the strain at working pressure meets the stress ratio requirements. For hybrid construction, the strain at working pressure is compared with the rupture strain of cylinders reinforced with a single fibre type.

e) Method 2 (applies to all cylinders).

1) At zero pressure after winding and autofrettage, apply strain gauges and calibrate;
2) Measure strains at zero pressure, working pressure, and minimum burst pressure;
3) At zero pressure, after strain measurements are taken at working pressure and minimum burst pressure and with strain gauges monitored, cut the cylinder section apart so that the region containing the strain gauge is approximately 125 mm long. Remove the liner without damaging the composite. Measure the strains after the liner is removed;
4) Adjust the strain readings at zero pressure, working pressure and minimum burst pressure by the amount of strain measured at zero pressure with and without the liner; and
5) Confirm that the strain at minimum burst pressure divided by the strain at working pressure meets the stress ratio requirements. For hybrid construction, the strain at working pressure is compared with the rupture strain of cylinders reinforced with a single fibre type.

ANNEX D

(*Clause* 4.4.1)

RATIONALE FOR NUMBER OF FILLING CYCLES

D-1 RATIONALE FOR NUMBER OF FILLING CYCLES

D-1.1 Personal Vehicles

D-1.1.1 *General*

The number of filling cycles that a cylinder should be capable of performing requires consideration of two scenarios of risk for material and system degradation, expected service and extended durability as shown in **D-1.1.2** and **D-1.1.3**.

D-1.1.2 *Expected Service*

The extreme stress case where the vehicle sustains only the most stressful (empty-to-full) fillings throughout its entire lifetime should be considered.

The maximum number of empty-to-full fillings in expected service is given by the following equation:

$$F_f = (L / R)$$

where

F_f = Maximum number of empty-to-full fillings in expected service;

L = Vehicle lifetime mileage in the expected service scenario; and

R = Vehicle driving range with a full cylinder.

Cylinders are required to demonstrate the capability to sustain this maximum number of lifetime empty-to-full filling events.

Under no circumstances should the maximum number of empty-to-full fillings in expected service be allowed to be less than 500 empty-to-full fillings, which is based on a vehicle lifetime mileage of 161 000 km and a vehicle driving range with a full cylinder of 322 km.

D-1.1.3 *Extended Durability*

The high usage case, where the vehicle sustains exposure to more severe (physical and chemical) environmental stresses and experiences a higher number of partial fillings throughout its entire lifetime, should also be considered.

Environmental stresses include abrasions and cuts associated with wear from vehicle attachments and from chemical exposures to chemically active constituents encountered in service (for example, acid rain slush, battery acid).

Cylinders are required to demonstrate the capability to sustain a minimum number of lifetime partial filling events.

The minimum number of partial fillings is given by the following equation:

$$F_P = [L / (R \times V)]$$

where

F_P = Maximum number of partial fillings in service;

L = Vehicle lifetime mileage in extended durability scenario;

R = Vehicle driving range with a full cylinder; and

V = Average fill volume fraction.

The minimum number of 5 500 filling cycles specified in **4.4.1** is based on the following assumptions:

a) A vehicle lifetime mileage in extended durability scenario of 590 000 km;
b) A vehicle driving range with a full cylinder of 322 km; and
c) An average fill volume fraction of 0.33.

An evaluation by the Sierra Research for the California Air Resource Board (2001) of vehicle lifetime mileage showed all scrapped vehicles had mileage below 563 000 km (the 3-sigma value, the 99.8 percentile, was 418 000 km, the 6-sigma value was 590 000 km). This is why the value of 590 000 km was selected for the vehicle lifetime mileage in extended durability scenario.

At present, all on-road vehicles produced by high volume vehicle manufacturers have a vehicle range with a full cylinder greater than 322 km.

Reliable statistics on current fill volume fraction are not available; statistics for hydrogen-fuelled vehicles will be influenced by the availability of hydrogen re-fuelling stations. The assumption was based on the fact that a lifetime of fillings needing less than 33 percent of full cylinder capacity provides a high-frequency extreme associated with a lifetime average of fillings on intervals of 106 km to 161 km travelled.

D-1.1.4 *Robustness (Safety Margin) of Extended Durability Design-Qualification Requirement*

The probability of a cylinder encountering the specified number of fillings is given by the multiplication of the probability that the vehicle lifetime mileage exceeds or is equal to 590 000 km ($Prob_1$) by the probability of having a vehicle driving range with a full cylinder equal to or less than 150 km ($Prob_2$) by the probability of having an average fill volume fraction of 0.33 for the vehicle lifetime ($Prob_3$). Estimates from data cited above indicate that $Prob_1$ and $Prob_2$ are each lower than 10^{-6}, ensuring that the result is below 10^{-12}.

A vehicle with a modest driving range of 150 km with a full cylinder would have to be driven over 825 000 km to require 5 500 empty-to-full fillings.

Low-volume partial fills cause markedly lower swings in temperature and pressure and, consequently, markedly lower stresses than empty-to-full filling stresses. Comprehensive data is not available (stresses an order of magnitude lower than empty-to-full fillings have been seen). Therefore, conducting the high-frequency filling pressure cycle tests using the reduced number of filling cycles specified in **4.4.1** with empty-to-full filling pressure swings provides a margin of robustness potentially in the order of 10.

D-1.2 Commercial Heavy-Duty Vehicles

Two factors distinguish the design qualification of cylinders for commercial heavy-duty (high usage) service.

Firstly, commercial fleet vehicles may experience extensive maintenance (such as engine and transmission overhauls) that significantly extend the vehicle lifetime mileage (vehicle range) and thereby increase the number of fillings during expected service.

Secondly, commercial fleet vehicles commonly remain in high-usage service for periods of 15 years or more. Fleet managers have requested certification of storage systems for 20 years to 25 years of service life. Additionally, commercial fleet vehicles may routinely experience daily empty-to-full fillings followed by immediate (overnight) parking such that the fuel pressure and temperature are not immediately relieved by subsequent driving.

Reflecting these differences, the requirements for pressure cycle testing for commercial heavy-duty vehicles assume the following:

a) The maximum number of empty-to-full fillings in expected service should be calculated using the equation given in **D-1.1.2**; however, this value may not be less than 1 000 cycles. This provides for commercial vehicles with twice the vehicle lifetime mileage in the expected service scenario of personal vehicles. If firm statistics on commercial vehicle lifetime mileage become available, this value may be revised in future editions of this document; and
b) In the extended durability scenario, the number of filling cycles should be calculated as according to the equation defined in **D-1.1.2**, but it should not be less than 11 250. In order to allow for unconstrained usage per year, the extreme condition of 2 empty-to-full fillings per day were assumed for continual full-day bus service. The minimum certification for commercial vehicles is specified as 15 years; hence, the minimum number of filling cycles is 2 empty-to-full fillings per day × 365 days per year × 15 years = 11 000. The robustness of this specification is assured by recognition that 11 000 filling cycles × 322 km/filling cycle exceeds 3.2 million km driven.

D-2 RATIONALE FOR PERMEATION RATES

The permeation value for light duty vehicles results from a European Commission Network of Excellence — HySafe — activity to estimate an allowable hydrogen permeation rate for automotive legal requirements and standards. The allowable permeation rate for hydrogen has been estimated based on a number of key assumptions.

a) A structure should be safe regardless of the vehicle that enters it (although what vehicle can physically enter the structure is a limit in itself);
b) The allowable permeation rate should be set so the vehicle is safe throughout its intended service life; and
c) The allowable permeation rate should not rely on regulations affecting the structure to ensure safety, that is safety be assured independent of the combination of vehicle and structure.

Accordingly, the specific assumptions used in the analysis includes the following:

a) Permeated hydrogen can be considered to disperse homogeneously.
b) Worst credible natural ventilation rate for a domestic garage is 0.03 air change per hour.
c) Maximum permitted hydrogen volume fraction in air 1 percent , that is 25 percent LFL.
d) Maximum long term material temperature is 55 °C.
e) New cylinder, with a factor of 2 to convert from the worst case end of life condition.

For a test conducted at a temperature of 20 °C, a factor of 3.5 is used to convert from the maximum prolonged material temperature to the test temperature (factor of 4.7 at 15 °C).

Based on the above assumptions, scenarios and methodology, the theoretical allowable permeation rates to give hydrogen volume fraction in air of less than 1 percent is 6.0 ml/h/l water capacity at a 15 °C minimum testing temperature.

D-3 CARBON FIBRE STRESS RATIO CONSIDERATIONS

It is considered safe to reduce the stress ratio for carbon fibre to as low as a factor of 2.0 for higher pressure designs based on a review of stress rupture data, in-service experience, and the fact that higher pressure tanks can tolerate a greater amount of external damage. For example, an examination of stress rupture data or composite strands (for example Robinson, 1991, Aerospace Corp Rpt 92 (2743)-1; Chiao et al., 1976, Lawrence Livermore National Laboratory (LLNL) UCRL 78367) shows that the probability of stress rupture at nominal working pressure stress is in the order of a billion years.

ANNEX E

(*Clauses* 5.2.6 *and* 7.5)

NDE DEFECT SIZE BY FLAWED CYLINDER CYCLING

E-1 The following procedure can be used to determine the non-destructive examination (NDE) defect size for metal liner or cylinder designs.

a) Introduce internal and external flaws. Internal flaws may be machined prior to the heat treatment and closing of the end of the cylinder;
b) Size these artificial defects to exceed the defect length and depth detection capability of the NDE inspection method; and
c) Pressure cycle three cylinders containing these artificial defects to failure in accordance with the test method specified in **H-5**.

If the cylinders do not leak or rupture in less than the number of filling cycles specified in **4.4**, then the allowable defect size for NDE is equal to or less than the artificial flaw size at that location.

In all cases, the reduction of cycle life due to the effect of hydrogen exposure should be considered. This could involve using the hydrogen gas cycling test procedure in XX.XXX.XX or a calculation approach using appropriate data.

ANNEX F

(*Clause* 5.3)

TYPE APPROVAL CERTIFICATE

F-1 This annex provides an example of a suitable form of a type approval certificate. Other formats also acceptable.

TYPE APPROVAL CERTIFICATE

Issued by

(Authorized Inspection Authority)

applying IS Standard

concerning

SEAMLESS STEEL GAS CYLINDERS

Approval No. : .... Date: ....

Type of cylinder : ....

(Description of the family of cylinders (Drawing No.) which has received type approval)

P_h ....bar, D_{min}..........................mm, D_{max}..........................mm, aA'. .... mm

Shape of base: ....*b* .... mm

L_{min}.......................mm, L_{max}.......................mm, V_{min}.......................litre, V_{max} .... litre

Material and heat treatment: ....

Material and characteristics; Material.........................R_e.....................MPa, R_g........................MPa

Manufacturer or agent: ....

(Name and address of manufacturer or its agent)

All information may be obtained from

(Name and address of approving body)

Date:........

Place:.......

(Signature Inspector)

ANNEX G

(*Clause* 9.2.3)

REQUIREMENTS FOR HYDROGEN BLENDS SERVICE

G-1 GENERAL

Tanks used for hydrogen blends service shall comply with all requirements of this standard, except as modified in **G-2** through **G-5**.

G-2 GAS COMPOSITION

Fuel tanks shall be designed to be filled with compressed gaseous hydrogen blends containing more than 2 percent hydrogen by volume, combined with dry natural gas. The gas composition shall comply with the composition given in **4.6**.

G-3 HYDROSTATIC BURST PRESSURE TEST

For the hydrostatic burst pressure test in **9.2.2.5**, the liner burst pressure shall exceed 1.3 times the nominal working pressure.

G-4 BONFIRE TEST

The bonfire test shall be carried out as per **H-7** except that under **H-7.2**, the cylinder shall be pressurized to the nominal working pressure with a hydrogen blend applicable to the design.

G-5 NATURAL GAS CYCLING TEST

The hydrogen gas cycling test in **H-13** shall instead be conducted using compressed natural gas complying with the composition specified in IS 15490.

ANNEX H

(*Clause* 9.2.3)

TEST METHODS AND ACCEPTANCE CRITERIA

H-1 ULTRA VIOLET RESISTANCE TEST

Protective coatings required to meet **H-8** shall be evaluated for resistance to ultraviolet effects using a minimum 1 000 h exposure using a UVA 340 lamp in accordance with ASTM G154. Evidence of blistering, cracking, chalking or softening shall be a cause for rejection.

H-2 HYDROGEN COMPATIBILITY TESTS

Hydrogen compatibility of the cylinder or liner material shall be demonstrated by one of the following:

a) Demonstrating the hydrogen compatibility of the material in accordance with IS/ISO 11114-4 for tanks with a nominal working pressure of 25 MPa; or
b) Cylinder shall qualify the hydrogen gas cycling test performed as per **H-13**.

H-3 RESIN PROPERTIES TESTS

For Type 2, Type 3, and Type 4 designs, resin shear strength shall be tested on three sample coupons representative of the composite over-wrap in accordance with ISO 15643. Following a 24 h water boil, the composite shall have a minimum shear strength of 13.8 MPa. For Type 2, Type 3, and Type 4 designs, resin glass transition temperature shall be determined in accordance with IS 101 (Part 8/Sec 2) or equivalent. The test results shall be within the manufacturer's specifications.

H-4 HYDROSTATIC BURST PRESSURE TEST

The cylinder shall be filled with a fluid such as water and the pressure shall be gradually increased until failure of the cylinder. The rate of pressurization shall not exceed 14 bar/s at pressures in excess of 150 percent of the working pressure. If the rate of pressurization at pressures in excess of 150 percent of the working pressure exceeds 3.5 bar/s, either the cylinder shall be placed schematically between the pressure source and the pressure measuring device or there shall be a five second hold at the minimum design burst pressure.

Unless different burst test criteria are specified for different test methods, the actual cylinder burst pressure shall exceed the minimum burst pressure given in **9.2.3.3** for the applicable cylinder design. In no case shall the burst pressure be less than the value necessary to meet the stress ratio requirements in Table 2. Actual burst pressure shall be recorded.

A leak or rupture may occur in either the cylindrical region or the dome region of the cylinder.

H-5 AMBIENT TEMPERATURE PRESSURE CYCLING

Pressure cycling shall be performed in accordance with the following procedure:

a) Fill the cylinder with a non-corrosive fluid such as oil, inhibited water or glycol;
b) Cycle the pressure in the cylinder between (20 ± 10) bar and 125 percent of working pressure at a rate not exceeding 10 cycles per min for the following number of cycles:

1) Category A cylinders: Number of cycles equivalent to 1 500 times the service life of the cylinder in years;
2) Category B cylinders: Number of cycles equivalent to 11 000, 15 000 or 22 000 cycles for a 15- year service life; and
3) Category C cylinders: Number of cycles equivalent to 2 250 times the service life of the cylinder in years.

Acceptable results

a) Category A: Cylinders shall not leak before reaching a number of cycles equivalent to 750 times and shall not rupture before reaching 1 500 times the service life of the cylinder in years.

b) Category B: Cylinders shall not leak before reaching a number of cycles equivalent to 5 500, 7 500 or 11 000 cycles and shall not rupture before reaching 11 000, 15 000 or 22 000 cycles for a 15 year service life.

c) Category C: Cylinders shall not leak before reaching a number of cycles equivalent to 1 125 times, and shall not rupture before reaching 2 250 times the service life of the cylinder in years.

d) For Type 2, Type3, and Type 4 cylinders, the fibers in the overwrap are not allowed to fail.

NOTE — It is acceptable for the pressurizing fluid to rise above the ambient temperature as long as the temperature of the test chamber and the fluid do not exceed the maximum specified temperature of the cylinder.

H-6 LEAK-BEFORE-BREAK (LBB) TEST

This test only applies to Type 1 and Type 2 cylinders. The cylinder shall be filled with a non-corrosive fluid such as oil, inhibited water or glycol and hydraulically pressure cycled from not more than (20 ± 10) bar to not less than 150 percent of the working pressure at a maximum rate of 10 cycles per min in accordance with **H-5**. The cylinder shall fail by leakage or shall exceed the number of filling cycles specified in **4.4**.

H-7 FIRE TEST

H-7.1 General

The fire test is designed to demonstrate that finished fuel tanks, complete with the cylinder manufacturer specified fire protection system, will not rupture when tested under specified fire conditions.

Precautions shall be taken during fire testing in the event that a cylinder rupture occurs.

H-7.2 Set-Up

H-7.2.1 *Test Procedure*

The cylinder shall be pressurized to the nominal working pressure with hydrogen and placed horizontally with the cylinder bottom approximately 100 mm above the fire source.

For the first part of the test (localized fire), the fire source shall be placed so that only the localized fire exposure area is exposed. The localized fire exposure area is defined as the area of a length of

(250 ± 50) mm, covering the entire diameter of the cylinder (width), measured from the point on the longitudinal axis of the cylinder located furthest from the non-reclosing thermally activated pressure relief device, part of the cylinder manufacturer specified fire protection system.

For the second part of the test (engulfing fire), the fire source shall cover up to a length of 1.65 m.

In both cases, the fire source shall provide direct flame impingement on the cylinder surface across its entire diameter (width). Metallic shielding of at least 0.4 mm thickness shall be used to prevent direct flame impingement on cylinder valves, fittings, and/or pressure relief devices. The metallic shielding shall not be in direct contact with the cylinder manufacturer specified non-reclosing thermally activated pressure relief devices.

A minimum 5 thermocouples shall be used to record the cylinder surface temperature on a maximum length of 1.65 m. At least 2 thermocouples shall be placed within the localized fire area. At least 3 thermocouples, equally spaced and not more that 0.5 m apart, shall be placed in the remaining area. All thermocouples shall be located adjacent to the outside surface of the cylinder along its longitudinal axis. Metallic shielding of 0.4 mm minimum thickness shall be used to prevent direct flame impingement on the thermocouples.

H-7.3 Fire Source

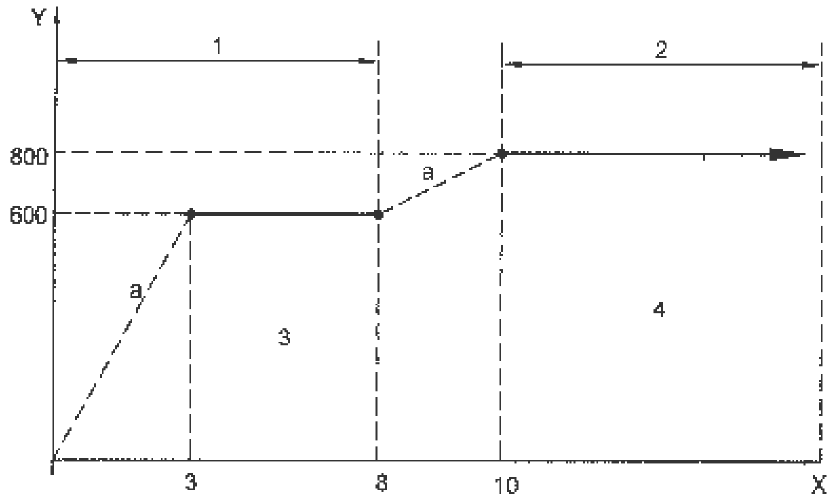
The fire source, which shall consist of liquefied petroleum gas (LPG) burners, shall produce a uniform minimum temperature on the tank surface. Wind shields shall be applied to ensure uniform heating.

The arrangement of the fire shall be recorded in detail to ensure the rate of heat input to the cylinder is reproducible.

H-7.4 Test Procedure

Within 3 min of ignition, the localized fire exposure area shall be exposed to a temperature of at least 600 °C, which shall be maintained for the next 5 min. The temperature outside the localized fire exposure area is not specified during the first 8 min of ignition. Then within the next 2 min interval, the cylinder shall be exposed to a minimum temperature of 800 °C and the fire source shall be extended to produce a fully-engulfing fire along the entire length and width of the tank (*see* Fig. 2).

Thermocouple temperatures and cylinder pressure shall be recorded at intervals of every 10 s or less during the test. Temperature requirements shall be deemed to be met when the 1 min moving average of recorded temperatures for each thermocouple, measured during periods of constant heat input, meets the specified temperature requirements. Any failure to maintain the specified temperature requirements during a test shall invalidate the result and the test shall be repeated.



X Elapsed time after ignition (min)
Y Measured Temperature (°C)
1 Localized fire
2 Engulfing fire
3 Localized fire exposure area
4 Region outside the localized fire exposure area
A The temperature increase shall be continuous. It does not need to be linear.

FIG. 2 SEQUENCE OF THE LOCALIZED FIRE TEST

H-7.5 Acceptable Results

The cylinder content shall vent through the non-reclosing thermally activated pressure relief device, part of the cylinder manufacturer specified fire protection system, continually (without interruption) until the pressure falls to less than 1 MPa. Alternatively, the cylinder shall be held at temperature (engulfing fire condition) for 30 min. In both cases, the cylinder shall not rupture. An additional release through leakage (not including release through the non-reclosing thermally activated pressure relief device) that results in a flame with length greater than 0.5 m beyond the perimeter of the applied flame shall be cause for rejection.

H-8 CHEMICAL EXPOSURE TEST

H-8.1 Pre-Conditioning

The following chemical exposure test procedure shall be performed on a finished cylinder, including the coating if applicable.

The upper section of the cylinder shall be divided into five distinct areas and marked for pendulum impact preconditioning and fluid exposure (*see* Fig. 3). The five areas shall each be nominally 100 mm in diameter. The five areas do not need to be oriented along a single line, but they shall not overlap.

The approximate centre of each of the five areas shall be preconditioned by the impact of a pendulum body. The steel impact body of the pendulum shall have the shape of a pyramid with equilateral triangle faces and a square base, the summit and the edges being rounded to a radius of 3 mm. The centre of percussion of the pendulum shall coincide with the centre of gravity of the pyramid; its distance from the axis of rotation of the pendulum being 1 m and the total mass of the pendulum referred to its centre of percussion shall be 15 kg. The energy of the pendulum at the moment of impact shall not be less than 30 J. During pendulum impact, the cylinder shall be held in position by the end bosses or by the intended mounting brackets. The cylinder shall not be under pressure during preconditioning.

H-8.2 Exposure to Chemicals

Each of the five preconditioned areas shall be exposed to one of five solutions (each solution shall be used and applied to only one preconditioned area). The five solutions are the following:

a) Volume fraction of 19 percent sulphuric acid in water;
b) Mass fraction of 25 percent sodium hydroxide in water;
c) Volume fraction of 5 percent methanol in gasoline;
d) Mass fraction of 28 percent ammonium nitrate in water; and
e) Volume fraction of 50 percent methyl alcohol in water (that is windscreen washer fluid).

During the exposure, orient the test cylinder with the fluid exposure areas on top. Place a pad of glass wool approximately 0.5 mm thick and 100 mm in diameter on each of the five preconditioned exposure areas. Apply an amount of the test fluid to the glass wool sufficient to ensure that the pad is wetted evenly across its surface and through its thickness for the duration of the test.

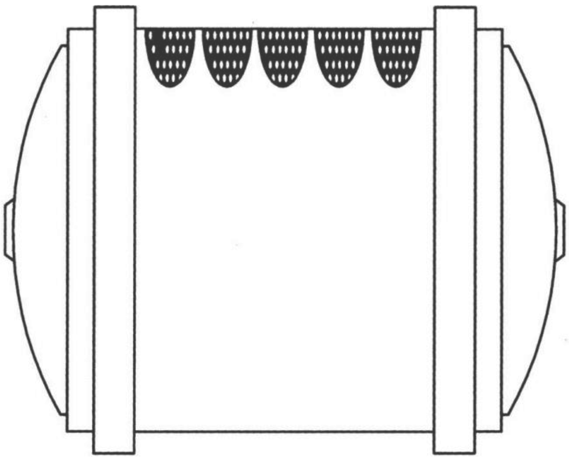


FIG. 3 FUEL TANK ORIENTATION AND LAYOUT OF EXPOSURE AREAS

H-8.3 Pressure Cycling

The cylinder shall then be filled with a non-corrosive fluid such as oil, inhibited water or glycol and hydraulically pressure cycled between (20 ± 10) bar and 125 percent of working pressure for a total of 3 000 cycles with maximum. Pressurization rate 27.5 bar per second. After pressure cycling, the cylinder shall be pressurized to 1.25 times the working pressure and held at that pressure for a minimum of 24 h. Until elapsed exposure time to environmental fluid (pressure hold + cycling) is minimum of 48 h.

H-8.4 Acceptance Criteria

When burst tested in accordance with **H-4**, the cylinder shall have a burst pressure that exceeds 1.8 times the working pressure.

H-9 FLAW TOLERANCE TESTS

H-9.1 Sampling

One finished cylinder shall be subjected to flaw tolerance test.

For Type 1 cylinders:

a) One uncoated cylinder shall have two saw cuts in the longitudinal direction cut into the cylinder sidewall. One flaw shall be minimum 25 mm long and minimum 0.42 mm deep and the other flaw shall be minimum 200 mm long and minimum 0.25 mm deep.

For Type 2, Type 3, and Type 4 cylinders:

b) One uncoated cylinder shall have two flaws in the longitudinal direction cut into the composite sidewall. One flaw shall be minimum 25 mm long and minimum 1.25 mm deep and the other flaw shall be minimum 200 mm long and minimum 0.75 mm deep.

H-9.2 Test Procedure

The flawed cylinder shall then be filled with a non-corrosive fluid such as oil, inhibited water or glycol and pressure cycled between (20 ± 10) bar and 125 percent of working pressure at ambient temperature for the number of filling cycles specified in **4.4**.

H-9.3 Acceptance Criteria

The cylinder shall not leak or rupture within the first 3 000 filling cycles specified in **4.4**, but may fail by leakage during the maximum number of filling cycles specified in **4.4**.

H-10 ACCELERATED STRESS RUPTURE TEST

The cylinder shall be hydrostatically pressurized to125 percent of working pressure ± 10 bar at 85 °C. The cylinder shall be held at this pressure and temperature for 1 000 h. At the completion of test the cylinder shall then be pressurised to burst in accordance with the procedure specified in **H-4**, its burst pressure shall exceed 75 percent of the minimum burst pressure, and residual burst strength of cylinder shall be no less than 180 percent of working pressure.

H-11 EXTREME TEMPERATURE PRESSURE CYCLING

The finished cylinder, with the composite wrapping shall be cycle tested in accordance with the following procedure.

a) Stabilize the cylinder at 85 °C or higher.
b) Hydrostatically pressurize for 4 000 filling cycles for Category A cylinders and 4 500 cycles for Category B cylinders between (20 ±10) bar and 125 percent of working pressure, at 85 °C or higher as measured on the cylinder surface;
c) Stabilize the cylinder at ambient conditions.
d) Stabilize the cylinder and fluid at –40 °C or lower as measured in the fluid and on the cylinder surface; and

e) Pressurize from 20 bar ± 10 bar to 80 percent of working pressure for 4 000 filling cycles for Category A cylinders and 4 500 cycles for Category B cylinders at –40 °C or lower. Adequate recording instrumentation shall be provided to ensure the minimum temperature of the fluid and cylinder surface is maintained during the low temperature cycling.

The pressure cycling rate shall not exceed 10 cycles per min.

During this pressure cycling, the cylinder shall show no evidence of rupture or leakage.

Following pressure cycling at extreme temperatures, cylinders shall be hydrostatically pressured to failure in accordance with **H-4** and achieve a minimum burst pressure that exceeds 180 percent of the minimum working pressure.

H-12 DROP TEST

H-12.1 Test Procedure

For Type 2, Type 3, or Type 4 cylinders, one or more finished cylinders shall be drop tested at ambient temperature without internal pressurization or attached valves. All drop tests may be performed on one cylinder, or individual impacts on a maximum of 3 cylinders. A plug may be inserted in the threaded ports to prevent damage to the threads and seal surfaces.

The surface on to which the cylinders are dropped shall be a smooth, horizontal concrete pad or flooring or similar rigid surface:

a) One cylinder shall be dropped in a horizontal position with the lowest point of cylinder no less than 1.83 m above the surface on to which it is dropped;
b) One cylinder shall be dropped vertically on each end at a sufficient height above the floor or pad so that the potential energy is 488 J, but in on case shall the height of the lower end be greater than 1.83 m; and
c) One cylinder shall be dropped at a 45° angle on to a dome, from a height such that the centre of center of gravity is at 1.83 m; however, if the lower end is closer to the ground than 0.6 m, the drop angle shall be changed to maintain a minimum height of 0.6 m and a centre of gravity of 1.83 m; above the impact surface.

No attempt shall be made to prevent the bouncing of cylinder, but the cylinders may be prevented from toppling during the vertical drop test.

H-12.2 Acceptance Criteria

Following the drop impact, the cylinders shall then be pressure cycled between (20 ± 10) bar and 125 percent of working pressure at ambient temperature, for the number of filling cycles specified in **4.4**.

The cylinder(s) shall not leak or rupture within first 3 000 filling cycles specified in **4.4**, but may fail by leakage during the remaining test cycles. All cylinders which complete this test shall be destroyed.

H-13 HYDROGEN GAS CYCLING TEST

H-13.1 Sampling

One finished cylinder shall be subjected to the hydrogen gas cycling test.

H-13.2 Procedure

The hydrogen gas cycling test shall be performed in accordance with the following procedure.

The cylinder shall be pressure cycled using hydrogen from (2 ± 1) MPa to 125 percent of the nominal working pressure for 1 000 cycles. The end boss at the valve end (the end where the fill/discharge occurs) may be grounded. Each cycle shall consist of filling and venting of the cylinder. The fill rate shall not exceed 60 g/s and the maximum allowable gas temperature shall not be exceeded. The defueling rate shall be specified by the cylinder manufacturer.

The first 500 cycles shall be conducted at the ambient temperature, followed by a static hold at 115 percent of the nominal working pressure ±1 MPa at 55 °C for a minimum of 30 h. The second 500 cycles shall be conducted with the cylinder at an ambient temperature of −30 °C (250 cycles) and at 50 °C (250 cycles).

Subscale specimens may be used for this test with diameters reduced by as much as 20 percent and lengths reduced by as much as 50 percent.

H-13.3 Acceptable Results

Following the completion of the test, the cylinder shall meet the requirements of the leak test in **H-16**. Type 4 cylinders shall then be sectioned and the liner and liner/end boss interface inspected for evidence of any deterioration, such as fatigue cracking, disbonding of plastic, deterioration of seals or damage from electrostatic discharge.

H-14 HARDNESS TEST

Hardness tests shall be carried out at three places on the parallel wall, at the centre and nearer to domed ends of each cylinder or liner in accordance with IS 1500 (Part 1) or using an equivalent method. The test shall be carried out after the final heat treatment and the hardness values thus determined shall be in the range specified for the design.

H-15 HYDRAULIC TEST

Any internal pressure applied after autofrettage and prior to the hydraulic test shall not exceed 90 percent of the hydraulic test pressure.

The hydraulic test shall be performed in accordance with the following procedure:

a) Option 1 — Volumetric expansion test:
   1) The cylinder shall be hydrostatically tested to at least 1.5 times working pressure. In no case shall the test pressure exceed the autofrettage pressure;
   2) Pressure shall be maintained for 30 s or sufficiently longer to ensure complete expansion. Any internal pressure applied after autofrettage and prior to the hydrostatic test shall not exceed 90 percent of the hydrostatic test pressure. If the test pressure cannot be maintained due to failure of the test apparatus, it is permissible to repeat the test at a

pressure increased by 7 bar. No more than 2 such repeat tests are permitted; and

3) Any cylinders not meeting the defined rejection limit shall be rejected and rendered unserviceable.

b) Option 2 — Proof pressure test:

1) The hydrostatic pressure in the cylinder shall be increased gradually and regularly until the test pressure, at least 5/3 times working pressure is reached. The cylinder test pressure shall be maintained for at least 30 s to establish that there is no leak.

H-16 LEAK TEST

Cylinders shall be leak tested in accordance with the following procedure, permeation through the wall shall not be considered to be leakage.

a) Thoroughly dry the cylinder; and
b) Pressurize the cylinder to working pressure with hydrogen or nitrogen containing a detectable gas such as helium.

Any leakage detected beyond the permeation rate shall be cause for rejection.

H-17 COATING BATCH TESTS

H-17.1 Coating Thickness

The thickness of the coating shall be measured in accordance with IS 101 (Part 3/Sec 2) and shall meet the requirements of the design.

H-17.2 Coating Adhesion

The coating adhesion strength shall be measured in accordance with IS 101 (Part 5/Sec 2) and shall have a minimum rating of 4 when measured using either test Method A or Method B, as appropriate.

H-18 PERMEATION TEST

H-18.1 Sampling

This test shall only be required on Type 4 cylinders.

One finished cylinder shall be subjected to the permeation test.

H-18.2 Procedure

The permeation test shall be performed in accordance with the following procedure.

Cylinders may be located in enclosed spaces for extended periods of time.

One cylinder shall be filled with hydrogen to the nominal working pressure (±1 MPa), placed in an enclosed sealed cylinder at (15 ± 5) °C. The test shall continue until the measured permeation reaches a steady state based on at least 3 consecutive readings separated by at least 12 h being within ±10 percent of the previous reading.

H-18.3 Acceptable Results

The steady state permeation rate for hydrogen gas shall be less than 6.0 Ncc of hydrogen per hour per liter water capacity.

NOTE — For the purposes of this document, the combination of permeation and leakage, if below the allowable permeation rate according to **H-18**, constitutes compliance with the permeation requirements, and if above the allowable permeation rate according to **H-18**, constitutes lack of compliance with the permeation requirements.

H-19 BOSS TORQUE TEST

H-19.1 Sampling

This test shall only be required on Type 4 cylinders.

One finished cylinder shall be subjected to the boss torque test.

H-19.2 Procedure

One cylinder shall be preconditioned with the boss subjected to twice the installation torque specified for the fittings. The cylinder shall then be subjected to **H-16**.

H-19.3 Acceptable Results

Any gas detected beyond the allowable permeation rate shall be a cause for rejection.

H-20 HIGH STRAIN RATE IMPACT TEST

H-20.1 Procedure

A cylinder shall be pressurized to the nominal working pressure (±1 MPa) with nitrogen, helium or hydrogen and be impacted by either:

a) A 7.62 mm diameter armor-piercing projectile (specified as 7.62 mm × 51 mm NATO, armor piercing bullet) with a nominal velocity of 850 m/s. The bullet shall be fired from a distance of no more than 45 m; or
b) A steel projectile having a minimum hardness of 870 Hv, with a diameter between 6.08 mm and 7.62 mm, having a mass of between 3.8 g and 9.75 g, a conical shape with a nose angle of 45°, a nominal velocity of 850 m/s and impacting with a minimum energy of 3 300 J.

The projectile shall impact the sidewall of the cylinder at a 90° angle but shall not be required to pass through the sidewall of the cylinder.

H-19.2 Acceptable Results

The cylinder shall not rupture.