भारतीय मानक
Indian Standard

IS 15935 : 2021

मोटर वाहन के लिए ईंधन के रूप में संपीडित प्राकृतिक गैस (सीएनजी) के ऑन-बोर्ड भंडारण हेतु संमिश्र सिलेंडर — विशिष्टि

(पहला पुनरीक्षण)

Composite Cylinders for On-Board Storage of Compressed Natural Gas (CNG) as a Fuel for Automotive Vehicle — Specification

(First Revision)

ICS 23.020;43.060.40

भारतीय मानक ब्यूरो
BUREAU OF INDIAN STANDARDS
मानक भवन, 9 बहादुरशाह ज़फर मार्ग, नई दिल्ली – 110002
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI-110002
www.bis.gov.in www.standardsbis.in

February 2021 **Price Group 14**

Gas Cylinders Sectional Committee, MED 16

FOREWORD

This Indian Standard (First Revision) was adopted by the Bureau of Indian Standards, after the draft finalized by the Gas Cylinders Sectional Committee had been approved by the Mechanical Engineering Division Council.

This standard was originally published in 2011. In this revision following major changes have been done:

a) Scope has been modified;
b) New terminology has been added;
c) Service life clause has been modified;
d) Gas composition clause has been modified; and
e) Certain other changes for better implementation of this standard.

Cylinders for the on-board storage of fuel for natural gas vehicle service are required to be light-weight, at the same time maintaining or improving on the level of safety currently existing for other pressure vessels.

The purpose of this standard is to specify minimum requirements for serially produced light-weight, composite refillable gas cylinder intended for the on-board storage for high pressure compressed natural gas as a fuel for automotive vehicles. This standard covers the metal and non-metal lined composite cylinders of the following types:

a) *Type 2* — Metal lined hoop wrapped composite cylinders;
b) *Type 3* — Metal lined full wrapped composite cylinders; and
c) *Type 4* — Non-metal lined full wrapped composite cylinders.

The type 1 metal cylinders are covered in IS 15490.

In the formulation of this standard considerable assistance has been taken from the following:

ISO 11439 : 2013	Gas cylinder — High pressure cylinders for the on-board storage of natural gas as a fuel for automotive vehicles
ANSI/CSA NGV2	Basic Requirements for compressed natural gas vehicle (NGV2) fuel containers
ISO 7866 : 1999	Gas Cylinders — Refillable seamless aluminum alloy gas cylinders — Design, construction and testing
ISO 14130 : 1997	Fiber reinforced plastic composite — Determination of apparent inter laminar shear strength by short-beam method
NACE/TM 0177 : 2005	Laboratory Testing of metals for resistance to sulfide stress cracking in H_2S environment at ambient temperature
ISO 7539-6 : 2003	Corrosion of metals and alloys — Stress corrosion testing — Part 6 Preparation and use of pre-cracked specimens for tests under constant load or constant displacement
ISO 11119-1 : 2002	Gas cylinders of composite construction — Specification and test methods Part 1: Hoop wrapped composite cylinders
ISO 11119-2 : 2002	Gas cylinders of composite construction — Specification and test methods Part 2: Fully wrapped fiber reinforced composite gas cylinders with load sharing metal liners

Since IS 15490 is a standalone standard for 'metal cylinders', we have to make this another standalone standard so as to cover all types of cylinders in Indian Standard as are covered in a single ISO standard 11439.

While implementing this standard, the manufacturer and the inspection agency shall ensure compliance with statutory regulations.

(*Continued to third cover*)

Indian Standard

COMPOSITE CYLINDERS FOR ON-BOARD STORAGEOF COMPRESSED NATURAL GAS (CNG) AS A FUEL FOR AUTOMOTIVE VEHICLE — SPECIFICATION

(First Revision)

1 SCOPE

This standard specifies minimum requirements for serially produced light-weight, refillable gas cylinder intended for the on-board storage of high pressure compressed natural gas as a fuel for automotive vehicles to which the cylinders are to be fixed. The service conditions do not cover external loadings which may arise from vehicle collisions, etc. This standard covers metal and non-metal lined composite cylinders of the following types:

a) Type 2 Metal lined hoop wrapped composite cylinders;

b) Type 3 Metal lined full wrapped composite cylinders; and

c) Type 4 Non-metal lined full wrapped composite cylinders.

2 REFERENCES

The following standards 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 indicated below:

IS No./ Other Publications	*Title*
101 (Part 3/Sec 2) : 1989	Methods of sampling and test for paints, varnishes and related products: Part 3 Tests on paint film formation, Section 2 Film thickness (*third revision*)
1500 (Part 1) : 2013	Metallic materials — Brinell hardness test: Part 1 Test method (*fourth revision*)
1586 (Part 1) : 2018	Metallic materials — Rockwell hardness test: Part 1 Test method (*fifth revision*)
1608 (Part 1) : 2018	Metallic materials — Tensile testing: Part 1 Method of test at ambient temperature (*fourth revision*)
1757 (Part 1) : 2014	Metallic materials — Charpy pendulum: Part 1 Test method (*fourth revision*)
3224 : 2002	Valve fittings for compressed gas cylinders exceeding liquefied petroleum gas (LPG) cylinders — Specification (*third revision*)
5903 : 2014	Recommendation for safety devices for gas cylinders (*first revision*)
13360 (Part 5/Sec 1) : 2018	Plastics — Methods of testing: Part 5 Mechanical properties, Section 1 Determination of tensile properties — General principles (*first revision*)
13360 (Part 5/Sec 2) : 2017	Plastics — Methods of testing: Part 5 Mechanical properties, Section 2 Determination of tensile properties test condition for moulding and extrusion plastics (*first revision*)
13360 (Part 6/Sec 1) : 2018	Plastics — Methods of testing: Part 6 Thermal properties, Section 1 Determination of vicat softening temperature of thermoplastic materials (*second revision*)
13411 : 1992	Glass reinforced polyester dough moulding compounds — Specification

IS No./ Other Publications	*Title*
15490 : 2017	Seamless steel cylinders for on-board storage of compressed natural gas as a fuel for automotive vehicles — Specification (*first revision*)
15660 : 2017	Refillable transportable seamless aluminium alloy gas cylinders — Specification (*first revision*)
15958 : 2012	Compressed natural gas (CNG) for automotive purposes — Specification
15975 : 2013	Gas cylinders — Conditions for filling gas cylinders
16087 : 2016	Biogas (bio-methane) — Specification (*first revision*)
ASTM D3170 : 2003	Standard test method for chipping resistance of coating
ASTM D3418 : 2015	Standard test method for transition temperatures and enthalpies of fusion and crystallization of polymers by differential scanning calorimetry
NACE TM 0177 : 2005	Laboratory testing of metals for resistance to sulphide stress cracking and stress corrosion cracking in H_2S

3 TERMINOLOGY

For the purpose of this standard, the following terms and definitions 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 overwrap 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 200 cylinders plus cylinders for destructive testing or one shift of successive production, whichever is greater.

3.5 Batch (of Metallic Liners) — Group of liners successively produced having the same 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. A batch shall be a group of 200 liners plus liners for destructive testing or one shift of successive production, whichever is greater.

3.6 Batch (of Non-metallic Liners) — Group of nonmetallic 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 200 liners 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 or non-metallic liner.

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

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 Filling Pressure — Pressure to which a cylinder is filled.

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

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

3.13 Gas Temperature — Temperature of gas in a cylinder.

3.14 Hoop Wrapped Cylinder — Cylinder with an overwrap having a filament wound reinforcement in a substantially circumferential pattern over the cylindrical portion of the liner so that the filament does not carry any significant load in a direction parallel to the cylinder longitudinal axis.

3.15 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 liner. Metallic liners are designed to share the load with the reinforcement and non-metallic liners do not carry any part of the load.

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

3.17 Pre-stress or Pre-stressing — The process of applying Autofrettage or controlled tension winding.

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

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

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

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

3.22 Test Pressure — Required pressure applied during a pressure test. This shall be 1.5 x working pressure.

3.23 Working Pressure — Settled pressure of 200 bar at a uniform temperature of 15 °C.

3.24 Type-2 Design — A hoop wrapped cylinder with a load sharing metal liner and composite reinforcement on the cylinder part only.

3.25 Type-3 Design — A fully wrapped cylinder with a load sharing metal liner and composite reinforcement on both the cylindrical part and dome ends.

3.26 Type-4 Design — A fully wrapped cylinder with anon-load sharing liner and composite reinforcement on both the cylindrical part and dome ends.

4 SERVICE CONDITION

4.1 General

4.1.1 *Standard Service Conditions*

The standard service conditions in this clause are provided as the basis for the design, manufacture, inspection, testing and approval of cylinders that are to be mounted permanently on vehicles and used to store natural gas at ambient temperature for use as a fuel on the vehicles.

4.1.2 *Use of Cylinders*

The service conditions specified are also intended to provide information on how cylinders which are manufactured in accordance with this standard may safely be used. This information is intended for:

a) Manufacturers of cylinders;
b) Owners of cylinders;
c) Designers or contractors responsible for the installation of cylinders;
d) Designers or owners of equipment used to refuel vehicle cylinders;
e) Suppliers of natural gas; and
f) Regulatory authorities who have jurisdiction over cylinder use.

4.1.3 *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 herein. The maximum service life shall be 20 years.

For all composite cylinders, the service life shall be demonstrated by appropriate design methods, design qualification testing and manufacturing controls.

The requirements for periodic re-qualification by inspection or testing during the service life shall be specified by the cylinder designer in consultation with statutory authority on the basis of use under service conditions.

Periodic inspection of cylinders shall be done at interval as per IS 15975 or as specified by the statutory authority.

4.2 Maximum Pressures

This standard is based upon a working pressure of 200 bar settled at 15 °C for natural gas as a fuel with a maximum filling pressure of 260 bar. Other working pressures may be accommodated by adjusting the pressure by the appropriate factor (ratio), for example, a 250 bar working pressure system will require 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 working pressure that would settle to 200 bar at a settled temperature of 15 °C; and
b) The maximum pressure in the cylinder shall not exceed 260 bar regardless of filling conditions or temperature.

4.3 Design Number of Filling Cycles

Cylinders shall be designed to be filled up to a settled pressure of 200 bar at a settled gas temperature of 15 °C for up to 1 000 times per year of service.

4.4 Temperature Range

4.4.1 *Gas Temperature*

Cylinder shall be designed to be suitable for the following gas temperature limits:

a) The settled temperature of gas in cylinders, which may vary from a low of – 20 °C to a high of + 65 °C.
b) The developed temperatures of gas in cylinders during filling and discharge, which may vary beyond the settled temperature limits for short periods.

4.4.2 *Cylinder Temperature*

Cylinder shall be designed to be suitable for the following material temperature limits:

a) Temperature of the cylinder materials may vary from – 20 °C to + 82 °C.
b) Temperatures over + 65 °C shall be sufficiently local, or of short enough duration, that the temperature of gas in the cylinder never exceeds + 65 °C, except under the conditions of **4.4.1** (b).

4.5 Gas Composition

4.5.1 *General*

Cylinders shall be designed to tolerate being filled with natural gas meeting the requirements of either IS 15958 for CNG or IS 16087 for biogas based on the gas to be filled.

The gas may contain compressor oil to the extent of 1 mg/kg of gas.

4.6 External Surfaces

It is not necessary for cylinders to be designed for continuous exposure to mechanical or chemical attack, for example, leakage from cargo that may be carried on vehicles or severe abrasion damage from road conditions. However, cylinder external surfaces shall be designed to with-stand inadvertent exposure to the following consistent with installation being carried out in accordance with the instructions to be provided with the cylinder.

Mechanical or chemical attack may result from environments, such as:

a) Water, either by intermittent immersion or road spray, or from cargo in vehicle;
b) Salt, due to the operation of the vehicle near the ocean or where ice-melting salt used;
c) Ultra-violet radiation from sunlight;
d) Impact of gravel;
e) Solvents, acids and alkalis, fertilizers;
f) Automotive fluids, including petrol, hydraulic fluids, battery acid, glycol and oils; and
g) Exhaust gases.

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**, and inspection and testing in accordance with either **6, 7** or **8** as appropriate to the construction. This shall be carried out by an authorized inspection authority. Test procedures are detailed in Annex A and Annex B.

5.2 Type Approval Procedure

5.2.1 *General*

Type approval consists of following two 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 **6.5** or **7.5** or **8.5** 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**; and
f) Additional supporting data, in accordance with **5.2.8**.

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) A statement that the cylinder design is suitable for use in the service conditions defined in **4** for the service life of the cylinder;
b) A statement of the service life;
c) The minimum periodic inspection requirements;

d) A specification for the pressure relief devices;
e) A specification for the support methods, protective covering and any other items required but not provided;
f) A description of the cylinder, such as, fiber(s), type, number of layers etc.; and
g) 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, manufacturer, reference number, date of issue, and revision numbers with dates of issue, if applicable;
b) Reference to this standard and the cylinder type;
c) All cylinder dimensions complete with tolerances, including details of end closure shapes with minimum thicknesses, openings and neck threads;
d) Water capacity and mass (including any permanent attachments), complete with tolerance of cylinders;
e) Material specifications, mechanical and chemical properties (including tolerances where applicable) and, for metal liners, the specified hardness range;
f) Other data, such as, working pressure, auto-frettage pressure, test pressure, minimum design burst pressure, design life; and
g) Details of the fire protection system and of any exterior protective coating.

5.2.4.2 *Stress analysis report*

A finite element stress analysis or other stress analysis shall be carried out. A table stresses shall be provided.

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 pressure relief devices that will protect the cylinder from sudden rupture when exposed to the fire conditions specified in **A-14** shall be specified. Test data shall substantiate the effectiveness of the specified fire protection system.

NOTE — The manufacturer may specify alternative PRD locations for specific vehicle installations.

5.2.5 *Manufacturing Data*

Details of all fabrication processes, non-destructive examinations, production tests and batch tests shall be provided. The tolerances for all production process, such as, heat treatment, end forming, resin-mix ratio, filament tension and speed for controlled tension winding, curing times and temperatures, and autofrettage procedures shall be specified.

Surface finish, thread details, acceptance criteria for ultrasonic examination (or equivalent) and maximum lot sizes for batch tests shall also be specified.

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

The manufacturer shall specify the maximum defect size for non-destructive examination that will ensure leak-before-break (LBB) fracture performance and will prevent failure by leakage or rupture of the cylinder during its service life. The maximum defect size shall be established by a method suitable to the design.

NOTE — An example of a suitable method is given in Annex C.

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 having organization stamp signed or initialed 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.

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 may be provided.

5.3 Type Approval Certificate

If the results of the design approval according to **5.2** and the prototype testing according to **6.5** or **7.5** or **8.5** as appropriate to the particular cylinder design are satisfactory, the inspector shall forward the test report for approval of the statutory authority.

6 REQUIREMENTS FOR METAL-LINED HOOP WRAPPED CYLINDERS (TYPE 2)

6.1 General

This standard does not provide design formula nor list permissible stresses or strains, but requires the adequacy of the design to be established by appropriate calculations and demonstrated by testing, to show that the cylinders shall pass the materials, design qualification, production and batch tests specified in this standard.

During pressurization, this type of cylinder design exhibits behaviour in which the displacements of the composite overwrap and the metal liner are superimposed.

The design shall ensure a leakage-before-break failure mode during normal service.

6.2 Materials

6.2.1 *General Requirements*

Material used shall be suitable for the service conditions specified in **4**. The design shall ensure that incompatible materials are not in contact.

6.2.2 *Controls on Chemical Composition*

6.2.2.1 *Steel*

Steel shall be aluminium and/or silicon-killed and produced to predominantly fine grain practice. The chemical composition of all steel shall be declared and defined by at least:

a) Carbon, manganese, aluminium, and silicon contents in all cases; and
b) Chromium, nickel, molybdenum, boron and vanadium contents and that of any other alloying elements intentionally added.

The sulphur and phosphorus content in the cast analysis shall not exceed the values given in Table 1.

Table 1 Maximum Sulphur and Phosphorus Limits in Steel

(*Clause* 6.2.2.1)

Sl No.	Element	Percent by Mass
(1)	(2)	(3)
i)	Sulphur	0.010
ii)	Phosphorus	0.020
iii)	Sulphur + Phosphorus	0.025

6.2.2.2 *Aluminium*

Aluminium alloys may be used to produce liners provided they meet all requirements of this standard and have maximum lead and bismuth contents not exceeding 0.003 percent total.

6.2.3 *Composite Materials*

6.2.3.1 *Resins*

The material for impregnation may be thermosetting or thermoplastic resin. Examples of suitable matrix materials are epoxy, modified epoxy, polyester and vinyl ester thermosetting plastics, and polyethylene and polyamide thermoplastic material.

The glass transition temperature of the resin material shall be determined in accordance with ASTM D 3418.

6.2.3.2 *Fibres*

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

The manufacturer shall keep on file the published specification for fibre material, the material manufacturer's recommendations for storage, conditions and shelf life and the material manufacturer's certification that each shipment conforms to said specification requirements.

The fibre manufacturer shall certify that the fibre material properties conform to the manufacturer's specification for the product.

6.3 Design Requirements

6.3.1 *Test Pressure*

The minimum test pressure used in manufacture shall be 300 bar (1.5 times working pressure).

6.3.2 *Burst Pressure and Fibre Stress Ratios*

The metal liner shall have a minimum actual burst pressure of 260 bar (1.3 times working pressure).

The minimum actual burst pressure of the finished cylinder shall be not less than the values given in Table 2. 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. The stress ratio calculations shall include the following:

a) An analysis method with capability for nonlinear materials (special purpose computer programme or finite element analysis programme);
b) Correct modelling of the elastic-plastic stress-strain curve for a known liner material;
c) Correct modelling of the mechanical properties of composite material;
d) Calculations at autofrettage pressure, zero pressure after autofrettage, working pressure and minimum burst pressure;
e) Account for the pre-stresses from winding tension;
f) The minimum burst pressure, chosen such that the calculated stress at minimum burst pressure divided by the calculated stress at working pressure meets the stress ratio requirements for the fibre used; and

g) Consideration of the load share between the different fibres based on the different elastic moduli of the fibres when analyzing cylinders with hybrid reinforcement (two or more different 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 outlined in Annex D.

Table 2 Minimum Actual Burst Values and Stress Ratios for Metal-Lined Hoop Wrapped Cylinders (Type 2)

(*Clauses* 6.3.2 *and* 6.5.2.4)

Sl No.	Fibre Type	Stress Ratio	Burst Pressure (bar)
(1)	(2)	(3)	(4)
i)	Glass	2.75	500[1)]
ii)	Aramid	2.35	470
iii)	Carbon	2.35	470
iv)	Hybrid[2)]	–	–

1) Minimum actual burst pressure. In addition, calculations shall be performed in accordance with **6.3.2** to confirm that the minimum stress ratio requirements are also met.

2) Stress ratios and burst pressure shall be calculated in accordance with **6.3.2**.

6.3.3 *Stress Analysis*

The stresses in the composite and in the liner after pre-stress shall be calculated for 0 bar, 200 bar, test pressure and design burst pressure. The calculations shall use suitable analysis techniques taking into account non-linear material behaviour of the liner when establishing stress distributions.

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

6.3.4 *Maximum Defect Size*

The maximum defect size at any location in the metal liner is such that the cylinder meets pressure cycling and LBB requirements shall be specified. The NDE method shall be capable of detecting the maximum defect size allowed. The allowable defect size for NDE shall be determined by an appropriate method, for example, as described in Annex C.

6.3.5 *Openings*

Openings are permitted in heads only. The centre line of openings shall coincide with the longitudinal axis of the cylinder.

6.3.6 *Fire Protection*

The cylinder design shall be protected with pressure relief devices. The cylinder, its materials, pressure relief devices and any added insulation or protective material shall be designed collectively to ensure adequate safety during fire conditions in the test specified in **A-14**. A manufacturer may specify alternative PRD locations for specific vehicle installations in order to optimise the safety considerations which shall be approved by statutory authority. Pressure relief devices shall conform to IS 5903.

6.4 Construction and Workmanship

6.4.1 *General*

The composite cylinder shall be manufactured from a seamless metallic liner over wrapped with continuous filament windings. Fibre winding operations shall be computer or mechanically controlled. The fibres shall be applied under controlled tension during winding. After winding is completed, thermosetting resins shall be cured by heating using a pre-determined and controlled time-temperature profile.

6.4.2 *Liner*

The manufacture of a metallic liner shall meet the requirements given in **6.2**, **6.3.2** and either **6.5.2.2** or **6.5.2.3** for the appropriate type of liner construction. Each liner shall be examined for thickness and the surface finish before end forming operations are carried out. The base ends of aluminium liners shall not be manufactured from tube. The base ends of steel liners that have been closed by forming shall be NDE inspected or equivalent. Metal shall not be added in the process of closure at the ends.

6.4.3 *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. Threads shall be clean cut, even, without chatter, answering to gauges and concentric with the axis of the cylinder.

6.4.4 *Overwrap*

6.4.4.1 *Fibre winding*

The cylinders shall be manufactured by a fibre winding technique. During winding the significant variables shall be monitored within specified tolerances and documented in a winding record. These variables can include but are not limited to:

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; and
k) winding angle.

6.4.4.2 *Curing of the thermosetting resins*

If a thermosetting resin is used, the resin shall be cured after filament winding. During the curing, the curing cycle (that is, the time temperature history) shall be documented. The maximum curing time and temperature for cylinders with aluminium alloy liners shall be below the time and temperature, which adversely affect metal properties.

6.4.4.3 *Autofrettage*

Autofrettage, if used, shall be carried out before the hydrostatic pressure test. The autofrettage pressure shall be within the limits established in **6.3.3** and the manufacturer shall establish the method of verifying the appropriate pressure.

6.4.5 *Exterior Environmental Protection*

The exterior of cylinders shall meet the requirement of the acid environment test described in **A-13**. Exterior protection may be provided by using any of the following:

a) A surface finish giving adequate protection (for example, metal sprayed on to aluminium, anodizing);
b) The use of a suitable fibre and matrix material (for example, carbon fibre in resin);
c) A protective coating (for example, organic coating, paint); if exterior coating is part of the design, the requirements of **A-9** shall be met; or
d) A covering impervious to the chemicals listed in **A-13**.

Any coatings applied to cylinders shall be such that the application process does not adversely affect 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.

An environmental performance test that evaluates the suitability of coating systems is provided in Annex E (Informative).

6.5 Prototype Testing Procedure

6.5.1 *General Requirements*

Prototype testing shall be conducted for each new design, on liners and/or finished cylinders, which are representative of normal production and complete with identification marks. The test liners or cylinders shall be selected and the prototype tests detailed in **6.5.2** verified/witnessed by the inspector. If more cylinders or liners are subjected to the tests than are required by this standard, all results shall be documented.

6.5.2 *Prototype Tests* **6.5.2.1** *Test required*

In the course of the type approval, the inspector shall select the necessary cylinders or liners for testing and witness the following tests:

a) Liner material tests specified in **6.5.2.2** or **6.5.2.3** as appropriate on one liner;
b) Hydrostatic pressure burst test specified in **6.5.2.4** on one liner and three cylinders;
c) Ambient temperature pressuring cycling test specified in **6.5.2.5** on two cylinders;
d) LBB test specified in **6.5.2.6** on three cylinders;
e) Bonfire test specified in **6.5.2.7** on one or two cylinders as appropriate;
f) Penetration test specified in **6.5.2.8** on one cylinder;
g) Acid environmental test specified in **6.5.2.9** on one cylinder;
h) Flaw tolerance test specified in **6.5.2.10** on one cylinder;
j) High temperature creep test specified in **6.5.2.11** where appropriate on one cylinder;
k) Accelerated stress rupture test specified in **6.5.2.12** on one cylinder;
m) Extreme temperature pressure cycling test specified in **6.5.2.13** on one cylinder; and
n) Resin shear strength test specified in **6.5.2.14** on one sample coupon representative of the composite overwrap.

6.5.2.2 *Material tests for steel liners*

Material tests shall be carried out on steel liners as follows:

a) *Tensile Test* — The material properties of the steel in the finished liner shall be determined in accordance with **A-1** and shall meet the requirements there in.
b) *Impact Test* — The impact properties of the steel in the finished liner shall be determined in accordance with **A-2** and shall meet the requirements there in.
c) *Sulphide Stress Cracking Resistance Test* — If the upper limit of the specified tensile strength for the steel exceeds 950 MPa, the steel from a finished cylinder/liner shall be subjected to a sulphide stress cracking resistance test in accordance with **A-3** and meet the requirements there in.
d) *Hardness Test* — Hardness of sample liners shall be recorded by testing on parallel wall at the

centre. None of the results shall be outside the limits specified on the design drawing.

Hardness testing shall be carried out in accordance with IS 1500 (Part 1) or IS 1586. The indenter and applied load shall be such that it shall not damage the cylinder. The test shall be carried out after final heat treatment.

Test values for hardness at the top, mid-section and base have been specified for those processes where cylinders are quenched by vertical immersion into the quench tank. Where the cylinders are immersed horizontally into the quenchant, hardness test shall be carried out at two points around the cylindrical mid-section of the parallel wall.

The hardness values obtained thus shall be in the range specified for the design.

The cylinders which are found to have hardness value beyond the specified range shall be subjected to appropriate re-heat treatment to achieve the hardness values within specified range.

6.5.2.3 *Material tests for aluminium alloy liners*

Material tests shall be carried out on aluminium alloy liners as follows:

a) *Tension Test* — The material properties of the aluminium alloy in the cylinder shall be determined in accordance with **A-1** and shall meet the requirements therein.
b) *Corrosion Test* — Aluminum alloys shall meet the requirement of the corrosion test carried out in accordance with **A-4**.
c) *Sustained Load Cracking Tests* — Aluminum alloys shall meet the requirements of the sustained load cracking test carried out in accordance with **A-5**.

6.5.2.4 *Hydrostatic pressure burst test*

a) One liner shall be hydrostatically pressurized to failure in accordance with **A-11**. The burst pressure shall exceed the minimum burst pressure specified for the liner design.
b) Three cylinders shall be hydrostatically pressurized to failure in accordance with **A-11**. The burst pressure shall exceed the minimum burst pressure calculated by the stress analysis for the design, in accordance with Table 2, and in no case be less than the value necessary to meet the stress ratio requirements of **6.3.2.**

6.5.2.5 *Ambient temperature pressure cycling test*

Two cylinders shall be pressure cycled to failure at ambient temperature in accordance with **A-12**, or to a minimum of 45 000 cycles. The cylinders shall not fail before reaching the specified service life in years multiplied by 1 000 cycles. Cylinders exceeding 1 000 cycles multiplied by the specified service life in years shall fail by leakage and not by rupture. Cylinders which do not fail within 45 000 cycles shall be destroyed either by continuing the cycling until failure occurs, or by hydrostatically pressurizing to burst or by drilling holes in side wall.

Cylinders exceeding 45 000 cycles are permitted to fail by rupture. The number of cycles to failure and the location of the failure initiation shall be recorded. If cylinder is destroyed, mode of destruction and photograph to be recorded.

6.5.2.6 *Leak-before-break (LBB) test*

The LBB test shall be carried out in accordance with **A-6** and shall meet the requirement therein.

6.5.2.7 *Bonfire test*

One or two cylinders as appropriate shall be tested in accordance with **A-14** and meet the requirement therein.

6.5.2.8 *Penetration test*

One cylinder shall be tested in accordance with **A-15** and meet the requirement therein.

6.5.2.9 *Acid environmental test*

One cylinder shall be tested in accordance with **A-13** and meet the requirement therein. An optional environmental test is included in Annex E.

6.5.2.10 *Flaw tolerance test*

One cylinder shall be tested in accordance with **A-16** and meet the requirement therein.

6.5.2.11 *High temperature creep test*

In designs, where the glass transition temperature of the resin does not exceed 102 °C, one cylinder shall be tested in accordance with **A-17** and meet the requirements therein.

6.5.2.12 *Accelerated stress rupture test*

One cylinder shall be tested in accordance with **A-18** and meet the requirements therein.

6.5.2.13 *Extreme temperature pressure cycling test*

One cylinder shall be tested in accordance with **A-7** and meet the requirements therein.

6.5.2.14 *Resin shear strength*

Resin material shall be tested in accordance with **A-25** and meet the requirements therein.

6.5.3 *Change of Design*

A design change is any change in the selection of structural materials or dimensional change not attributable to normal manufacturing tolerances. Minor design changes shall be permitted to be qualified through a reduced test programme. Changes of design specified in Table 3 shall require only the prototype testing as specified in the table.

A fibre material shall be considered to be of a new fibre type when:

a) the fibre is of a different classification, e.g. 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;

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:

e) the resin is of a different classification, for example, thermosetting or thermoplastic; or

f) the resin is of a different type of same classification of resin, for example, epoxy, polyester, polyethylene, polyamide.

Table 3 Change of Design for Metal-Lined-Hoop Wrapped Cylinders (Type 2)

(*Clause* 6.5.3)

Sl No.	Design Change	Type of Test								
		Hydro static Burst (See A-11)	*LBB (See A-6)*	*Pressure cycling at Ambient Temperature (See A-12)*	*Bon-fire (See A-14)*	*Penetration (See A-15)*	*Acid Environment (See A-13)*	*Composite Flaw Tolerance (See A-16)*	*High Temperature Creep (See A-17)*	*Accelerated Stress Rupture (See A-18)*
(1)	(2)	(3)		(4)	(5)	(6)	(7)	(8)	(9)	(10)
i)	Fibre manufacturer	X		X	—	—	—	—		X
ii)	Metallic liner material5)	X	X	X	X	X	X	X	X	X
iii)	Fibre material	X	X	X	X	X	X	X	X	X
iv)	Resin material	—	X	—	—	X	X	X	X	X
v)	Diameter change ≤ 20 Percent	X		X	—	X3)	—	—	—	—
vi)	Diameter change ≥ 20 Percent	X	X	X	X	X	—	X	—	—
vii)	Length change ≤ 50 Percent	X		—	X1)	—	—	—	—	—
viii)	Length change > 50 Percent	X		X	X1)	—	—	—	—	—
ix)	Working pressure change ≤ 20 Percent2)	X		X	—	—	—	—	—	—
x)	Dome shape	X	X4)	X	—	—	—	—	—	—
xi)	Opening size	X		X	—	—	—	—	—	—
xii)	Coating change						X			
xiii)	Manufacturing process	X		X	—	—	—	—	—	—
xiv)	Pressure relief device	—		—	X	—	—	—	—	—

1) Test only required when length increases.

2) Only when thickness change proportional to diameter and/or pressure change.

3) Only required if diameter decreases.

4) Only required for non-IS 7285-2 liner designs.

5) Material tests are also required.

6.6 Batch Tests on Liners and Cylinders

6.6.1 *General Requirements*

Batch testing shall be conducted on liners and on finished cylinders which are representative of normal production and are complete with permanent 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 by this standard, all results shall be documented. Where defects are detected in composite overwrap before any Autofrettage or hydrostatic pressure testing, the overwrap may be completely removed and replaced.

6.6.2 *Required Tests*

6.6.2.1 *Liner tests*

On a liner, or heat treated sample representative of a finished liner:

a) a check of the critical dimensions against the design (*see* **5.2.4.1**);
b) one tensile test in accordance with **A.1**; the test results shall satisfy the requirements of the design (*see* **5.2.4.1**);
c) for steel liners, three impact tests in accordance with **A.2**; the test results shall satisfy the requirements specified in **A.2**; and
d) for steel liners with a tensile strength exceeding 1 100 MPa, each new cast of material shall meet the requirements of the sulphide stress cracking test in **A.3**. A sample of material from each cast may be heat treated and tested by the steel supplier or cylinder manufacturer, provided that the samples have the same strength values specified in the cylinder design.

All liners represented by a batch test that fail to meet the requirements specified shall follow the procedures specified in **6.9.**

6.6.2.2 *Cylinder tests*

a) on one cylinder, one hydrostatic pressure burst test in accordance with **A.11**.
b) on a further cylinder:
    1) a check of the critical dimensions against the design (see **5.2.4.1**); and
    2) when a protective coating is a part of the design, a coating batch test in accordance with **A.24**.

Where the coating fails to meet the requirements of **A.24**, the batch shall be 100 percent inspected to remove similarly defectively coated cylinders. The coating on all defectively coated cylinders may be stripped using a method that does not affect the integrity of the composite wrapping then recoated. The coating batch test shall then be repeated.

6.6.2.3 Additionally, a periodic pressure cycling test shall be carried out on 1 finished cylinder in accordance with **A-12.** One cylinder from each batch shall be pressure cycled for a total of 1 000 times the specified service life in years, with a minimum of 15 000 cycles.

Should the cylinder under test in above fail to meet the minimum cycle life requirement of 1 000 cycles multiplied by the specified service life in years (minimum 15 000 cycles), then the cause of failure shall be determined and corrected in accordance with the procedure in **6.9**. The pressure cycle test shall then be repeated on an additional three cylinders from that batch. Should any of the three additional cylinders fail to meet the minimum pressure cycling requirement of 1 000 cycles multiplied by the specified service life in years, then the batch shall be rejected.

6.7 Tests on Every Liner and Cylinder

Production examinations and tests shall be carried out on all liners and cylinders produced in a batch.

Each liner shall be examined either during manufacture or after completion, as appropriate:

a) by NDE of metallic liners in accordance with Annex B or demonstrated equivalent method to verify that the maximum defect size does not exceed the size specified in the design as determined in accordance with **6.3.4**. The NDE method shall be capable of detecting the maximum size allowed;
b) to verify that the critical dimensions and mass of the liners are within design tolerances;
c) to verify conformance to 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;
d) by hardness tests of metallic liners in accordance with **A. 8** carried out after the final heat treatment. The values thus determined shall be in the range specified for the design;
e) Each cylinder shall be examined either during manufacture or after completion, as appropriate, to verify that the critical dimensions and mass of the completed cylinders and overwrapping are within design tolerances;
f) to verify the permanent identification marks;
g) by hydrostatic test of finished cylinders in accordance with **A-11**. The manufacturer shall establish the appropriate limit of permanent expansion for the test pressure used, but in no case shall the permanent expansion exceed 5 percent of the total volumetric expansion measured under the test pressure; and
h) by leak testing of cylinders with base ends formed by spinning. Typical testing procedures include

the pneumatic leakage test where the bottom end should be clean and free from all moisture on the test pressure side. The inside area of the cylinder bottom surrounding the closure should be subjected to a pressure equal to at least 2/3 times the test pressure of the cylinder for a minimum of 1 min. This area should be not less than 20 mm in diameter around the closure and at least 6 percent of the total bottom area. The opposite side should be covered with water or another suitable medium and closely examined for indication of leakage. Cylinders that leak should be rejected.

6.8 Batch Acceptance Certificate

If the results of batch testing according to **6.6** and **6.7** are satisfactory, the manufacturer and the inspector shall sign an acceptance certificate.

6.9 Failure to Meet Test Requirements

6.9.1 *Liners*

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

a) there is evidence of a fault in carrying out a test, or an error of measurement, a further test shall be performed if, the result of this test is satisfactory. The first test shall be ignored;
b) the test has been carried out in a satisfactory manner, the cause of test failure shall be identified if the failure is:
    1) considered to be due to the heat treatment applied, the manufacturer may subject all the liners implicated by the failure to a further heat treatment; however if the failure occurs sporadically in a test applied to every liner, then only those liners which fail the test shall require re-heat treatment and re-testing:
        i) Whenever liners are re-heat treated, the minimum guaranteed wall thickness shall be maintained.
        ii) Only the relevant prototype or batch tests needed to prove the acceptability of the new batch shall be performed again. If one or more tests prove even partially unsatisfactory, all liners of the batch shall be rejected, and not placed in service.
    2) due to a cause other than the heat treatment applied, all defective liners shall be either rejected or repaired by an approved method. Provided that the repaired liners pass the test(s) required for the repair, they shall be re-instated as part of the original batch.

6.9.2 *Cylinders*

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

a) if there is evidence of a fault in carrying out a test, or an error of measurement, a further test shall be performed, if the result of this test is satisfactory, the first test shall be ignored; or
b) if the test has been carried out in a satisfactory manner, the cause of test failure shall be identified.

All defective cylinders shall be either rejected or repaired by an approved method. Provided that the repaired cylinders pass the test(s) required for the repair, they shall be re-instated as part of the original batch.

7 REQUIREMENTS FOR METAL-LINED FULLY-WRAPPED CYLINDERS (TYPE 3)

7.1 General

This standard does not provide design formulae nor list permissible stresses or strains, but requires the adequacy of the design to be established by appropriate calculations and demonstrated by testing to show that the cylinders shall pass the materials, design qualification, production and batch tests specified in this standard.

During pressurization, this type of cylinder exhibits behaviour in which the displacements of the composite overwrap and the liner are superimposed. The design shall ensure a leakage-before-break failure mode during normal service.

7.2 Materials

7.2.1 *General Requirements*

Materials used shall be suitable for the service conditions specified in **4**. The design shall ensure that incompatible materials are not in contact with each other or the gas contained in cylinder.

7.2.2 *Controls on Chemical Composition*

7.2.2.1 *Steel*

Steel shall be aluminum and/or silicon-killed and produced to predominantly fine grain practice. The chemical composition of all steels shall be declared and defined by at least:

a) the carbon, manganese, aluminum, and silicon contents in all cases; and
b) the chromium, nickel, molybdenum, boron and vanadium contents, and that of any other alloying elements intentionally added.

The sulphur and phosphorus content in the cast analysis shall not exceed the values in Table 4.

Table 4 Maximum Sulphur and Phosphorus Limits

(*Clause* 7.2.2.1)

Sl No.	Element	Percent by Mass
(1)	(2)	(3)
i)	Sulphur	0.010
ii)	Phosphorus	0.020
iii)	Sulfur + phosphorus	0.025

7.2.2.2 *Aluminium*

Aluminium alloys may be used to produce liners provided they meet all requirements of this standard and have maximum lead and bismuth contents not exceeding 0.003 percent.

A list of permitted aluminium alloys is given in IS 15660.

7.2.3 *Composite Materials*

7.2.3.1 *Resin*

The material for impregnation may be thermosetting or thermoplastic resin. Examples of suitable matrix materials are epoxy, modified epoxy, polyester and vinyl-ester thermosetting plastics, and polyethylene and polyamide thermoplastic material.

The glass transition temperature of the resin material shall be determined in accordance with ASTM D 3418.

7.2.3.2 *Fibres*

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 the metallic components of the cylinder.

The manufacturer shall keep on file the published specification for fibre material, the material manufacturer's recommendations for storage, conditions and shelf life and the material manufacturer's certification that each shipment conforms to said specification requirements.

The fibre manufacturer shall certify that the fibre material properties conform to the manufacturer's specifications for the product.

7.3 Design Requirements

7.3.1 *Test Pressure*

The minimum test pressure used in manufacture shall be 300 bar (1.5 times working pressure).

7.3.2 *Burst Pressure and Fibre Stress Ratios*

The minimum actual burst pressure shall be not less than the values given in Table 5. 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 5. 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.

The stress ratio calculations shall include

a) an analysis method with capability for nonlinear materials (special purpose computer program or finite element analysis programme;

   5) correct modelling of the elastic-plastic stress strain curve for a known liner material;

   5) correct modelling of the mechanical properties of composite material;

e) calculations at Autofrettage pressure, zero pressure after Autofrettage, working pressure and minimum burst pressure;

   5) account for the pre-stresses from winding tension;

f) the minimum burst pressure, chosen such that the calculated stress at minimum burst pressure divided by the calculated stress at working pressure meets the stress ratio requirements for the fibre used; and

   5) consideration of the load share between the different fibres based on the different elastic moduli of the fibres when analyzing cylinders with hybrid reinforcement (two or more different fibres). The stress ratio requirements for each individual fibre type shall be in accordance with the values given in Table 5.

Verification of the stress ratios may also be performed using strain gauges. An acceptable method is outlined in Annex D.

Table 5 Minimum Actual Burst Values and Stress Ratios for Metal-Lined Fully Wrapped Cylinders (Type 3) (with a working pressure of 200 bar)

(*Clause* 7.3.2)

Sl No.	Fibre Type	Stress Ratio	Burst Pressure, bar
(1)	(2)	(3)	(4)
i)	Glass	3.65	700[1)]
ii)	Aramid	3.10	600
iii)	Carbon	2.35	470
iv)	Hybrid[2)]	–	–

1 Minimum actual burst pressure. In addition, calculations shall be performed in accordance with **7.3.2** to confirm that the minimum stress ratio requirements are also met.

2 Stress ratios and burst pressure shall be calculated in accordance with **7.3.2**.

7.3.3 *Stress Analysis*

A stress analysis shall be performed to justify the minimum design wall thicknesses. It shall include the determination of the stresses in liners and fibres of composite designs.

The stresses in the tangential and longitudinal direction of the cylinder in the composite and in the liner after pre-stress shall be calculated for 0 bar, 200 bar, test pressure and design burst pressure. The calculations shall use suitable analysis taking into account non-linear material behaviour of the liner when establishing stress distributions. The limits within which the Autofrettage pressure shall fall shall be calculated.

7.3.4 *Maximum Defect Size*

The maximum defect size at any location in the metal liner such that the cylinder meets pressure cycling and LBB requirements shall be specified. The NDE method shall be capable of detecting the maximum defect size allowed.

The allowable defect size for NDE shall be determined by an appropriate method (*see* Annex C).

7.3.5 *Openings*

Openings are permitted in heads only. The centre line of openings shall coincide with the longitudinal axis of the cylinder.

7.3.6 *Fire Protection*

The cylinder design shall be protected with pressure relief devices. The cylinder, its materials, pressure relief devices and any added insulation or protective material shall be designed collectively to ensure adequate safety during fire conditions in the test specified in **A-14**. A manufacturer may specify alternative PRD locations for specific vehicle installations in order to optimize safety considerations which shall be approved by statutory authority. Pressure relief devices shall conform to IS 5903.

7.4 Construction and Workmanship

7.4.1 *General*

The composite cylinder shall be manufactured from a seamless metallic liner overwrapped with continuous filament windings. Fibre winding operations shall be computer or mechanically controlled. The fibres shall be applied under controlled tension during winding. After winding is complete, thermosetting resins shall be cured by heating, using a predetermined and controlled time-temperature profile.

7.4.2 *Liner*

The manufacture of a metallic liner shall meet the requirements given in **7.2**, **7.3.2** and either **7.5.2.2** or **7.5.2.3** for the appropriate type of liner construction. Each liner shall be examined for thickness and the surface finish before end forming operations are carried out. The base ends of aluminium liners shall not be manufactured from tube. The base ends of steel liners that have been closed by forming shall be NDE inspected or equivalent. Metal shall not be added in the process of closure at the ends.

7.4.3 *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. Threads shall be clean cut, even, without chatter, answering to gauges and concentric with the axis of the cylinder.

7.4.4 *Overwrap*

7.4.4.1 *Fibre winding*

The cylinders shall be manufactured by a fibre winding technique. During winding the significant variables shall be monitored within specified tolerances and documented in a winding record. These variables can include but are not limited to:

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; and
k) Winding angle.

7.4.4.2 *Curing of the thermosetting resins*

If a thermosetting resin is used, the resin shall be cured after filament winding. During curing, the curing cycle (that is, the time temperature history) shall be documented. The maximum curing time and temperature for cylinders with aluminium alloy liners shall be below the time and temperature, which adversely affect metal properties.

7.4.4.3 *Autofrettage*

Autofrettage, if used, shall be carried out before the hydrostatic pressure test. The Autofrettage pressure shall be within the limits established in **7.3.3** and the manufacturer shall establish the method of verifying the appropriate pressure.

7.4.5 *Exterior Environmental Protection*

The exterior of cylinders shall meet the requirement of the acid environment test described in **A-13**. Exterior protection may be provided by using any of the following:

a) A surface finish giving adequate protection (for example, metal sprayed on to aluminum, anodizing);
b) The use of a suitable fibre and matrix material (for example, carbon fibre in resin);
c) A protective coating (for example, organic coating, paint), if exterior coating is part of the design, the requirements of **A-9** shall be met; or
d) A covering impervious to the chemicals listed in **A-13**.

Any coatings applied to cylinders shall be such that the application process does not adversely affect 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.

An environmental performance test that evaluates the suitability of coating systems is provided in Annex E.

7.4.6 *Traceability*

Materials of construction affecting cylinder performance, as determined by the manufacturer, shall be traceable to the extent required to recall cylinders, if necessary.

7.5 Prototype Testing Procedure

7.5.1 *General Requirements*

Prototype testing shall be conducted for each new design, on liners and/or finished cylinders, which are representative of normal production and complete with identification marks. The test cylinders or liners shall be selected and the prototype tests detailed in **7.5.2** (and detailed in Annex A) verified/witnessed by the inspector. If more cylinders or liners are subjected to the tests than are required by this standard, all results shall be documented.

7.5.2 *Prototype Tests*

7.5.2.1 *Test required*

In the course of the type approval, the inspector shall select the necessary cylinders or liners for testing and witness the following tests:

a) Liner material tests specified in **7.5.2.2** or **7.5.2.3** as appropriate on one liner;
b) Hydrostatic pressure burst test specified in **7.5.2.4** on three cylinders;
c) Ambient temperature pressuring cycling test specified in **7.5.2.5** on two cylinders;
d) LBB test specified in **7.5.2.6** on three cylinders;
e) Bonfire test specified in **7.5.2.7** on one or two cylinders as appropriate;
f) Penetration test specified in **7.5.2.8** on one cylinder;
g) Acid environmental test specified in **7.5.2.9** on one cylinder;
h) Flaw tolerance test specified in **7.5.2.10** on one cylinder;
j) High temperature creep test specified in **7.5.2.11** where appropriate on one cylinder;
k) Accelerated stress rupture test specified in **7.5.2.12** on one cylinder;
m) Extreme temperature pressure cycling test specified in **7.5.2.13** on one cylinder;
n) Resin shear strength test specified in **7.5.2.14** on one sample coupon representative of the composite overwrap; and
p) Drop test specified in **7.5.2.15** on one cylinder.

7.5.2.2 *Material tests for steel liners*

Material tests shall be carried out on steel liners as follows:

a) *Tensile Test* — The material properties of the steel in the finished liner shall be determined in accordance with **A-1** and shall meet the requirements therein.
b) *Impact Test* — The impact properties of the steel in the finished liner shall be determined in accordance with **A-2** and shall meet the requirements therein.
c) *Sulphide Stress Cracking Resistance Test* — If the upper limit of the specified tensile strength for the steel exceeds 950 MPa, the steel from a finished cylinder shall be subjected to a sulphide stress cracking resistance test in accordance with **A-3** and meet the requirements therein.
d) *Hardness Test* — Hardness of sample liners shall be recorded by testing on parallel wall at the centre. None of the results shall be outside the limits specified on the design drawing.

   Hardness testing shall be carried out in accordance with IS 1500 (Part 1) or IS 1586. The indenter and applied load shall be such that it shall not damage the cylinder. The test shall be carried out after final heat treatment.

   Test values for hardness at the top, mid-section and base have been specified for those processes where cylinders are quenched by vertical immersion into the quench tank. Where the cylinders are immersed horizontally into the quenchant, hardness test shall be carried out at two points around the cylindrical mid-section of the parallel wall.

   The hardness values obtained thus shall be in the range specified for the design.

   The cylinders which are found to have hardness value beyond the specified range shall be subjected to appropriate re-heat treatment to achieve the hardness values within specified range.

7.5.2.3 *Material tests for aluminium alloy liner*

Material tests shall be carried out on aluminium alloy liners as follows:

a) *Tension Test* — The material properties of the aluminium alloy in the cylinder shall be determined in accordance with **A-1** and shall meet the requirements therein.
b) *Corrosion Test* — Aluminum alloys shall meet the requirement of the corrosion test carried out in accordance with **A-4**.
c) *Sustained Load Cracking Tests* — Aluminum alloys shall meet the requirements of the sustained load cracking test carried out in accordance with **A-5**.

7.5.2.4 *Hydrostatic pressure burst test*

Three cylinders shall be hydrostatically pressurized to failure in accordance with **A-11**. The cylinder burst pressure shall exceed the specified minimum burst pressure established by the stress analysis for the design in accordance with Table 5 and in no case be less than the value necessary to meet the stress ratio requirements of **7.3.2**.

7.5.2.5 *Ambient temperature pressure cycling test*

Two cylinders shall be pressure cycled to failure at ambient temperature in accordance with **A-12**, or to a minimum of 45 000 cycles. The cylinders shall not fail before reaching the specified service life in years multiplied by 1 000 cycles. Cylinders exceeding 1 000 cycles multiplied by the specified service life in years shall fail by leakage and not by rupture. Cylinders which do not fail within 45 000 cycles shall be destroyed either by continuing the cycling until failure occurs, or by hydrostatically pressurizing to burst or by drilling holes in side wall.

Cylinders exceeding 45 000 cycles are permitted to fail by rupture. The number of cycles to failure and the location of the failure initiation shall be recorded. If cylinder is destroyed, mode of destruction and photograph to be recorded.

7.5.2.6 *Leak-before-break (LBB) test*

The LBB test shall be carried out in accordance with **A-6** and shall meet the requirement therein.

7.5.2.7 *Bonfire test*

One or two cylinders as appropriate shall be tested in accordance with **A-14** and meet the requirement therein.

7.5.2.8 *Penetration test*

One cylinder shall be tested in accordance with **A-15** and meet the requirement therein.

7.5.2.9 *Acid environmental test*

One cylinder shall be tested in accordance with **A-13** and meet the requirement therein. An optional environmental test is included in Annex E.

7.5.2.10 *Flaw tolerance test*

One cylinder shall be tested in accordance with **A-16** and meet the requirement therein.

7.5.2.11 *High temperature creep test*

In designs, where the glass transition temperature of the resin does not exceed 102 °C, one cylinder shall be tested in accordance with **A-17** and meet the requirements therein.

7.5.2.12 *Accelerated stress rupture test*

One cylinder shall be tested in accordance with **A-18** and meet the requirements therein.

7.5.2.13 *Extreme temperature pressure cycling test*

One cylinder shall be tested in accordance with **A-7** and meet the requirements therein.

7.5.2.14 *Resin shear strength*

Resin material shall be tested in accordance with **A-25** and meet the requirements therein.

7.5.2.15 *Drop test*

One (or more) finished cylinders shall be drop tested in accordance with **A-19** and meet the requirements therein.

7.5.3 *Change of Design*

A design change is any change in the selection of structural materials or dimensional change not attributable to normal manufacturing tolerances. Minor design changes shall be permitted to be qualified through a reduced test programme. Changes of design specified in Table 6 shall require design qualification testing as specified in Table 6.

A fibre material shall be considered to be of a new design when:

a) the fibre is of a different classification, e.g. 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;
d) the nominal fibre strength, specified by the fibre manufacturer, differs by more than ± 5 percent from that defined in the prototype tested design;
e) A resin material shall be considered to be a new resin type when:
    1) the resin is of a different classification, for example, thermosetting or thermoplastic; or
    2) the resin is of a different type of same classification of resin, for example, epoxy, polyester, polyethylene, polyamide.

Table 6 Change of Design for Metal-Lined-Hoop Wrapped Cylinders (Type 3)

(*Clause* 7.5.3)

Sl No.	Design Change	Type of Test										
		Hydro static Burst (See A-11)	*LBB (See A-6)*	*Pressure Cycling at Ambient Temperature (See A-12)*	*Bonfire (See A-14)*	*Penetration (See A-15)*	*Environmental (See A-13)*	*Flaw Tolerance (See A-16)*	*High Temperature Creep (See A-17)*	*Stress Rupture (See A-18)*	*Drop (See A-19)*	*Torque (See A-26)*
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
i)	Fibre manufacturer	X	X	X	—	—	—	—		X	X	
ii)	Metallic liner material	X	X	X	X	X	X	X	X	X	X	
iii)	Fibre material	X	X	X	X	X	X	X	X	X	X	
iv)	Resin material	—		—	—	**X**	**X**	**X**	**X**	**X**	**X**	
v)	Diameter change ≤ 20 percent	X	X	X	—	**X**[3]	—	—	—	—	—	
vi)	Diameter change ≥ 20 percent	X	X	X	X	**X**	—	**X**	—	—	**X**	
vii)	Length change ≤ 50 percent	X		—	X[1]	—	—	—	—	—	—	
viii)	Length change ≥ 50 percent	X	X	X	X[1]	—	—	—	—	—	**X**	
ix)	Working pressure change ≤ 20 percent[2]	X	X	X	—	—	—	—	—	—	—	
x)	Dome shape	X	X	X	—	—	—	—	—	—	—	
xi)	Opening size	X	X	X	—	—	—	—	—	—	—	
xii)	Change in manufacturing process	X	X	X	—	—	—	—	—	—	—	
xiii)	Coating change						**X**					
xiv)	Pressure relief device	—		—	X	—	—	—	—	—	—	
xv)	Thread											**X**

[1] Test only required when length increases.

[2] Only when thickness change proportional to diameter and/or pressure change.

[3] Only required if diameter decreases.

[4] Materials tests are also required

7.6 Batch Tests on Liners and Cylinders

7.6.1 *General Requirements*

Batch testing shall be conducted on liners, and on finished cylinders which are representative of normal production and are complete with permanent identification marks. The cylinders and liners required for testing shall be randomly selected from each batch. If more cylinders or liners are subjected to the tests than are required by this standard, all results shall be documented. Where defects are detected in overwrapping before any Autofrettage or hydrostatic pressure testing, the overwrapping may be completely removed and replaced.

7.6.2 *Requirements*

7.6.2.1 *Liner tests*

On a liner, or heat treated sample representative of a finished liner:

a) a check of the critical dimensions against the design (*see* **5.2.4.1**);
b) one tensile test in accordance with **A-1**, the test results shall satisfy the requirements of the design (*see* **5.2.4.1**);
c) for steel liners, three impact tests in accordance with **A-2**; the test results shall satisfy the requirements specified in **A-2**;
d) for steel liners with a tensile strength exceeding 1100 MPa, each new cast of material shall meet the requirements of the sulphide stress cracking test in **A.3**. A sample of material from each cast may be heat treated and tested by the steel supplier or cylinder manufacturer, provided that the samples have the same strength values specified in the cylinder design.

All liners represented by a batch test that fail to meet the requirements specified shall follow the procedures specified in **7.9.**

7.6.2.2 *Cylinder tests*

a) on one cylinder, one hydrostatic pressure burst test in accordance with **A-11**.
b) on a further cylinder:
   1) a check of the critical dimensions against the design (*see* **5.2.4.1**); and
   2) when a protective coating is a part of the design, a coating batch test in accordance with **A-24**. Where the coating fails to meet the requirements of **A-24**, the batch shall be 100 percent inspected to remove similarly defectively coated cylinders. The coating on all defectively coated cylinders may be stripped using a method that does not affect the integrity of the composite wrapping then recoated. The coating batch test shall then be repeated.

7.6.2.3 Additionally, a periodic pressure cycling test shall be carried out on 1 finished cylinder in accordance with **A-12.** One cylinder from each batch shall be pressure cycled for a total of 1 000 times the specified service life in years, with a minimum of 15 000 cycles.

7.7 Tests on Every Liner and Cylinder

Production examinations and tests shall be carried out as follows on all liners and cylinders produced in a batch. Nondestructive examinations shall be carried out in accordance with a standard approved by the inspector. Each liner and cylinder shall be examined during manufacture and after completion as follows:

a) By NDE of metallic liners in accordance with **Annex B** or demonstrated equivalent method to verify that the maximum defect size does not exceed the size specified in the design as determined in accordance with **7.3.4**. The NDE method shall be capable of detecting the maximum size allowed;
b) To verify that critical dimensions and mass of the completed cylinders and of the liners and over wrapping are within design tolerances;
c) 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;
d) To verify the permanent markings; and
e) By hardness tests of metallic liners in accordance with **A-8** carried out after the final heat treatment. The values thus determined shall be in the range of specified for the design.

7.7.1 *Cylinder Tests*

Each cylinder shall be examined either during manufacture and/or after completion, as appropriate:

a) to verify that the critical dimensions and mass of the completed cylinders and overwrapping are within design tolerances;
b) to verify the permanent identification marks;
c) by hydrostatic test of finished cylinders in accordance with **A-11**. The manufacturer shall establish the appropriate limit of permanent expansion for the test pressure used, but in no case shall the permanent expansion exceed 5 percent of the total volumetric expansion measured under the test pressure.
d) by leak testing of cylinders with base ends formed by spinning. Typical testing procedures include the pneumatic leakage test where the bottom

end should be clean and free from all moisture on the test pressure side. The inside area of the cylinder bottom surrounding the closure should be subjected to a pressure equal to at least 2/3 times the test pressure of the cylinder for a minimum of 1 min. This area should be not less than 20 mm in diameter around the closure and at least 6 percent of the total bottom area. The opposite side should be covered with water or another suitable medium and closely examined for indication of leakage. Cylinders that leak should be rejected.

7.8 Batch Acceptance Certificate

If the results of batch testing according to **7.6** and **7.7** are satisfactory, the manufacturer and the inspector shall sign an acceptance certificate.

7.9 Failure to Meet Test Requirements

7.9.1 *Liners*

In the event of failure to meet test requirements, retesting or re-heat treatment and re-testing shall be carried out as follow to the satisfaction of the inspector;

a) If there is evidence of a fault in carrying out a test, or an error of measurement, a further test 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 heat treatment applied, the manufacturer may subject all the cylinders implicated by the failure to a further heat treatment, that is, if the failure is in a test representing the batch cylinders, test failure shall require re-heat treatment of all the represented cylinders prior to re-testing.
    2) However, if the failure occurs sporadically in a test applied to every cylinder, then only those cylinder which fail the test shall require re-heat treatment and re-testing:
        i) Whenever liners are re-heat treated, the minimum guaranteed wall thickness shall be maintained.
        ii) Only the relevant batch test needed to prove the acceptability of the new batch shall be performed again. If one or more tests prove even partially unsatisfactory; all cylinders of the batch shall be rejected.
    3) If the failure is due to a cause other than the heat treatment applied, all defective cylinders shall be either rejected or repaired by an approved method. Provided that the repaired cylinders past he tests required for the repair, they shall be re-instated as part of the original batch.

7.9.2 *Cylinders*

In the event of failure of a cylinder to meet test requirements, re-testing shall be carried out:

a) if there is evidence of a fault in carrying out a test, or an error of measurement, a further test shall be performed, if the result of this test is satisfactory, the first test shall be ignored; and
b) if the test has been carried out in a satisfactory manner, the cause of test failure shall be identified.

All defective cylinders shall be either rejected or repaired by an approved method. Provided that the repaired cylinders pass the test(s) required for the repair, they shall be re-instated as part of the original batch.

8 REQUIREMENTS FOR NON-METAL-LINED COMPOSITE CYLINDERS (TYPE 4)

8.1 General

This standard does not provide design formulae nor list permissible stresses or strain, but requires the adequacy of the design to be established by appropriate calculations and demonstrated by testing to show that the cylinders shall pass the materials, design qualification, production and batch tests specified in this standard.

The design shall ensure a leakage-before-break failure mode during normal service.

8.2 Materials

8.2.1 *General Requirements*

Materials used shall be suitable for the service conditions specified in **4**. The design shall ensure that incompatible materials are not in contact with each other or with gas contained in cylinder.

8.2.2 *Resins*

The material for impregnation may be thermosetting or thermoplastic resin. Examples of suitable matrix materials are epoxy, modified epoxy, polyester and vinyl ester thermosetting plastics, and polyethylene and polyamide thermoplastic material.

The glass transition temperature of the resin material shall be determined in accordance with ASTM D3418.

8.2.3 *Fibres*

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 the metallic components of the cylinder.

The manufacturer shall keep on file the published specification for fibre material, the material manufacturer's recommendations for storage, conditions and shelf life and the material manufacturer's certification that each shipment conforms to said specification requirements.

The fibre manufacturer shall certify that the fibre material properties conform to the manufacturer's specification for the product.

8.2.4 *Plastic Liners*

The polymeric material shall be compatible with the service conditions specified in **4**.

8.2.5 *Metal End Bosses*

The metal end bosses connected to the non-metallic liner shall be of a material compatible with the service conditions specified in **4**.

8.3 Design Requirements

8.3.1 *Test Pressure*

The minimum test pressure used in manufacture shall be 300 bar (1.5 times working pressure).

8.3.2 *Burst Pressure and Fibre Stress Ratios*

The minimum actual burst pressure shall be not less than the values given in Table 7. 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 burst pressure of the cylinder divided by the working pressure.

For nonmetal lined full wrapped designs, the stress ratio is equal to the burst ratio.

For designs using hybrid reinforcement (two or more different fibres), the load share between the different fibres based on the different elastic moduli of the fibres shall be considered in the analysis. The stress ratio requirements for each individual fibre type shall be in accordance with the values given in Table 7.

Verification of the stress ratios may also be performed using strain gauges.

NOTE — An acceptable method is outlined in Annex D.

Table 7 Minimum Actual Burst Values and Stress Ratios for Non-metal-Lined Full Wrapped Cylinders (Type 4) (with Working Pressure of 200 bar)

(*Clauses* 8.3.2 *and* 8.5.2.3)

Sl No.	Fibre Type	Stress Ratio	Burst Pressure
(1)	(2)	(3)	(4)
i)	Glass	3.65	730
ii)	Aramid	3.10	620
iii)	Carbon	2.35	470
iv)	Hybrid[1)]	–	–

[1)] Stress ratios and burst pressures shall be calculated in accordance with **8.3.2.**

8.3.3 *Stress Analysis*

A stress analysis shall be performed to justify the minimum design wall thicknesses. It shall include the determination of the stresses in liners and fibres of composite designs. The stresses in the tangential and longitudinal direction of the cylinder composite and in the liner shall be calculated. The pressure used for these calculations shall be 0 bar, working pressure, test pressure and design burst pressure. The calculations shall use suitable analysis techniques to establish stress distribution throughout the cylinder.

8.3.4 *Openings*

Openings are permitted in the end bosses only. The centre line of openings shall coincide with the longitudinal axis of the cylinder.

8.3.5 *Fire Protection*

The cylinder design shall be protected with pressure relief devices. The cylinder, its materials, pressure relief devices and any added insulation or protective material shall be designed collectively to ensure adequate safety during fire conditions in the test specified in **A-14**. A manufacturer may specify alternative PRD locations for specific vehicle installations in order to optimize safety considerations which shall be approved by statutory authority. Pressure relief devices shall conform to IS 5903.

8.4 Construction and Workmanship

8.4.1 *General*

The composite cylinder shall be manufactured from anon-metallic liner overwrapped with continuous filament windings. Fibre winding operations shall be computer or mechanically controlled. The fibre shall be applied under controlled tension during winding. After winding is complete, thermosetting resins shall be cured by heating, using a predetermined and controlled time-temperature profile.

8.4.2 *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. Threads shall be clean cut, even, without surface discontinuities and concentric with the axis of the cylinder.

8.4.3 *Curing of the Thermosetting Resins*

The curing temperature for thermosetting resin shall be at least 10 °C below the softening temperature of the plastic liner.

8.4.4 *Exterior Environmental Protection*

The exterior of cylinders shall meet the requirement of the acid environment test described in **A-13**. Exterior protection may be provided by using any of the following:

a) A surface finish giving adequate protection (for example, metal sprayed on to aluminum, anodizing);
b) The use of a suitable fibre and matrix material (for example, carbon fibre in resin);
c) A protective coating (for example, organic coating, paint); if exterior coating is part of the design, the requirements of **A-9** shall be met; or
d) A covering impervious to the chemicals listed in **A-13**.

Any coatings applied to cylinders shall be such that the application process does not adversely affect 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.

An environmental performance test that evaluates the suitability of coating systems is provided in Annex E (Informative).

8.4.5 *Traceability*

Materials of construction affecting cylinder performance, as determined by the manufacturer, shall be traceable to the extent required to recall cylinders, if necessary.

8.5 Prototype Testing Procedure

8.5.1 *General*

Prototype testing shall be conducted for each new design, on finished cylinders, which are representative of normal production and complete with identification marks. The test cylinder or liners shall be selected and the prototype tests detailed in **8.5.2** (and detailed in Annex A) verified/witnessed by the inspector. If more cylinders or liners are subjected to the tests than are required by this standard, all results shall be documented.

8.5.2 *Prototype Tests*

8.5.2.1 *Test required*

In the course of the type approval, the inspector shall select the necessary cylinders or liners for testing and witness the following tests:

a) Liner material tests specified in **8.5.2.2** as appropriate on one liner;
b) Hydrostatic pressure burst test specified in **8.5.2.3** on three cylinders;
c) Ambient temperature pressuring cycling test specified in **8.5.2.4** on two cylinders;
d) LBB test specified in **8.5.2.5** on three cylinders;
e) Bonfire test specified in **8.5.2.6** on one or two cylinders as appropriate;
f) Penetration test specified in **8.5.2.7** on one cylinder;
g) Acid environmental test specified in **8.5.2.8** on one cylinder;
h) Flaw tolerance test specified in **8.5.2.9** on one cylinder;
j) High temperature creep test specified in **8.5.2.10** where appropriate on one cylinder;
k) Accelerated stress rupture test specified in **8.5.2.11** on one cylinder;
m) Extreme temperature pressure cycling test specified in **8.5.2.12** on one cylinder;
n) Resin shear strength test specified in **8.5.2.13** on one sample coupon representative of the composite overwrap;
p) Drop test specified in **8.5.2.14** on one cylinder;
q) Boss torque test specified in **8.5.2.15** on one cylinder;
r) Permeation test specified in **8.5.2.16** on one cylinder; and
s) Natural gas cycling test specified in **8.5.2.17** on one cylinder.

8.5.2.2 *Material tests for plastic liners*

The tensile yield strength and ultimate elongation shall be determined in accordance with **A-21** and shall meet the requirements therein. The softening temperature shall be determined in accordance with **A-22** and shall meet the requirements therein.

8.5.2.3 *Hydrostatic pressure burst test*

Three cylinders shall be hydrostatically pressurized to failure in accordance with **A-11**. The cylinder burst pressure shall exceed the specified minimum burst pressure established by the stress analysis for the liner design, in accordance with Table 7, and in no case less than the value necessary to meet the stress ratio requirements of **8.3.2**.

8.5.2.4 *Ambient temperature pressure cycling test*

Two cylinders shall be pressure cycle tested at ambient temperature in accordance with **A-12** to failure, or to a minimum of 45 000 cycles. The cylinders shall not fail before reaching the specified service life in years multiplied by 1 000 cycles. Cylinders exceeding 1 000 cycles multiplied by the specified service life in years shall fail by leakage and not by rupture. Cylinders which do not fail within 45 000 cycles shall be destroyed either by continuing the cycling until failure occurs, or by hydrostatically pressurizing to burst or by drilling holes in side wall. Cylinders exceeding 45 000 cycles are permitted to fail by rupture. The number of cycles to failure and the location of the failure initiation shall be recorded. If cylinder is destroyed, mode of destruction and photograph to be recorded.

8.5.2.5 *Leak-before-break (LBB) test*

The LBB test shall be carried out in accordance with **A-6** and shall meet the requirement therein.

8.5.2.6 *Bonfire test*

One or two cylinders as appropriate shall be tested in accordance with **A-14** and meet the requirement therein.

8.5.2.7 *Penetration test*

One cylinder shall be tested in accordance with **A-15** and meet the requirement therein.

8.5.2.8 *Acid environment test*

One cylinder shall be tested in accordance with **A-13** and meet the requirement therein.

8.5.2.9 *Flaw tolerance test*

One cylinder shall be tested in accordance with **A-16** and meet the requirement therein.

8.5.2.10 *High temperature creep test*

One cylinder shall be tested in accordance with **A-17** and meet the requirements therein.

8.5.2.11 *Accelerated stress rupture test*

One cylinder shall be tested in accordance with **A-18** and meet the requirements therein.

8.5.2.12 *Extreme temperature pressure cycling test*

One cylinder shall be tested in accordance with **A-7** and meet the requirements therein.

8.5.2.13 *Resin shear strength*

Resin material shall be tested in accordance with **A-25**, devices and meet the requirements therein.

8.5.2.14 *Drop test*

One (or more) finished cylinders shall be drop tested in accordance with **A-19** and meet the requirements therein.

8.5.2.15 *Boss torque test*

One cylinder shall be tested in accordance with **A-23** and meet the requirements therein.

8.5.2.16 *Permeation test*

One cylinder shall be tested for permeation in accordance with **A-20** and meet the requirements therein.

8.5.2.17 *Natural gas cycling test*

One cylinder shall be tested in accordance with **A-27** and meet the requirements therein.

8.5.3 *Change of Design*

8.5.3.1 A design change is any change in the selection of structural materials or dimensional change not attributable to normal manufacturing tolerances. Minor design changes shall be permitted to be qualified through a reduced test programme. Changes of design specified in Table 8 shall require design qualification testing as specified in Table 8.

8.5.3.2 Either a fibre material change or a fibre manufacturer change shall be considered to be of a new design and require full qualification when:

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; or
d) the nominal fibre strength, specified by the fibre manufacturer, differs by more than ±5 percent from that defined in the prototype tested design.

Fibre materials that are within the above limits are considered equivalent fibres and are eligible for the reduced test programme described in Table 10. Note that a change in fibre material does not require tests that evaluate the performance of plastic liners, for example, permeation testing and natural gas cycle testing.

8.5.3.3 A resin material shall be considered to be a new resin type when:

a) the resin is of a different classification, for example, thermosetting or thermoplastic, and
b) the resin is of a different type of same classification of resin, for example, epoxy, polyester, polyethylene, polyamide.

8.6 Batch Tests

8.6.1 Batch testing shall be conducted on finished cylinders which are representative of normal production and are 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 by this standard, all results shall be documented.

8.6.2 *Required Tests*

8.6.2.1 At least the following tests shall be carried out on each batch of cylinders:

a) On one cylinder, a hydrostatic pressure burst test is carried out in accordance with **A-11**. The burst pressure is less than the minimum calculated burst pressure, the procedures specified in **8.9** shall be followed.
b) On a further cylinder or liner representative of a finished cylinder:
    1) A check of the critical dimensions against the design (*see* **5.2.4.1**);
    2) One tensile test of the plastic liner in accordance with **A-21**, the test result shall satisfy the requirements of the design (*see* **5.2.4.1**); and
    3) The softening temperature of the plastic liner shall be tested in accordance with **A-22**, and the requirements of the design.
c) When a protective coating is a part of the design, a coating batch test in accordance with **A.24**. Where the coating fails to meet the requirements of **A.24**. The batch shall be 100 percent inspected to remove similarly defectively coated cylinders.

   The coating on all defectively coated cylinders may be stripped using a method that does not affect the integrity of the composite wrapping then recoated.

The coating batch test shall then be repeated.

8.6.2.2 *Failure to meet batch test requirements*

All cylinders or liners represented by a batch test which fail to meet the specified requirements shall follow the procedures specified in **8.9**.

8.6.2.3 Additionally, a periodic pressure cycling test shall be carried out on 1 finished cylinder in accordance with **A-12**. One cylinder from each batch shall be pressure cycled for a total of 1 000 times the specified service life in years, with a minimum of 15 000 cycles.

8.7 Tests on Every Cylinder

Production examinations and tests shall be carried out as follows on all cylinders produced in batch. Each cylinder shall be examined during manufacture and after completion as follows:

a) By inspection of liners to confirm that the maximum defect size present is smaller than the specified in the design;
b) To verify that critical dimensions and mass of the completed cylinders and of any liner and overwrapping are within design tolerances;
c) To verify compliance with specified surface finish;
d) To verify the markings;
e) By hydraulic test of finished cylinders in accordance with **A-10**. The manufacturer shall define the appropriate limit of elastic expansion for the test pressure used, but in no case shall the elastic expansion of any cylinder exceed the average batch value by more than 10 percent; and
f) By leak test in accordance with **A-9**, and shall meet the requirements therein.

8.8 Batch Acceptance Certificate

If the results of batch testing according to **8.6** and **8.7** are satisfactory, the manufacturer and the inspector shall sign an acceptance certificate.

NOTE — An example of an acceptance certificate (referred to as a "Report of Manufacture and Certificate of Conformance") is given in Annex D.

Table 8 Change of Design for Type 4 Cylinders

(*Clause* 8.5.3)

Design Change	Type of Test													
	Perme-ation	CNG Cycling	Hydro-static Burst	Boss Torque	LBB	Pressure Cycling at Ambient Tempe-rature	Bon-fire	Penetra-tion	Environ-mental	Flaw Tol-erance	High Tempe-rapture Creep	Stress Rup-ture	Impact Dam-age	Valve Torque
	(A.20)	(A.27)	(A.11)	(A.23)	(A.6)	(A.12)	(A.14)	(A.15)	(A.13)	(A.16)	(A.17)	(A.18)	(A.19)	(A.26)
Fibre manufacturer			X			X						X	X	
Plastic liner material	X	X	X	X			X				X		X	
Fibre material			X		X	X	X	X	X	X	X	X	X	
Resin material					X			X	X	X	X			
Diameter change ≤ 20 percent			X			X		X_e						
Diameter change >20 percentb			X		X	X	X	X		X			X	
Length change ≤ 50 percent			X				X_a							
Length change > 50 percent			X			X	X_a						X	
Working pressure change ≤ 20 percent			X			X								
Dome shape			X		X	X								
Opening size (com-posite)			X		X	X								
Coating change									X					
End boss design	X_c	X_c		X_d										
Pressure relief device							X							

[a] Test only required when length increases.

[b] Only when thickness change proportional to diameter and/or pressure change.

[c] Only if boss/liner interface is affected.

[d] Only if boss/liner or boss composite interface is affected or torque requirements change.

[e] Only required if diameter decreases.

8.9 Failure to Meet Test Requirements

In the event of failure to meet test requirements, retesting shall be carried out as follows:

a) If there is evidence of a fault in carrying out a test, or an error of measurement, a further test 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 by the following:

   1) All defective cylinders shall be rejected or repaired by an approval method. Provided that the repaired cylinders pass the test(s) required for the repair, they shall be re-instated as part of the original batch.

   2) The new batch shall be re-tested. All the relevant prototype or batch test needed to prove the acceptability of the new batch shall be performed again. If one or more tests prove even partially unsatisfactory, all cylinders of the batch shall be rejected.

9 MARKING

9.1 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 or any combination of the above. Multiple labels are allowed and should be located such that they are not obscured by mounting brackets. Each cylinder complying with this standard shall be marked as follow:

a) The words ‘CNG only’;

b) Expiry date. The words ‘DO NOT USE AFTER XX/XXXX’, where XX/XXXX identifies the month and 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 cylinders 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 at temperature;

f) Maximum temperature which the cylinder can sustain (This shall not be exceeded during filling, retesting and cleaning operations);

g) Reference to this standard, along with cylinder type and statutory authority’s approval numbers;

h) The words ‘Use only an manufacturer’s approved PRD’;

j) Date of manufacture (month and year);

k) Periodical retesting on XX – XX – XXXX; and

m) When labels are used, a unique identification number and the manufacturer’s identification stamped on an exposed metal surface to permit tracing in the event that the label is destroyed.

9.2 The marking shall be placed in the listed sequence but the specific arrangement may be varied to match the space available. An acceptable example is:

a) CNG only;

b) Do not use after 3/2009;

c) Manufacture/Identification number;

d) 200 bar/15°;

e) CIS 15935 : 2019 TYPE-2 (registration No.);

f) ‘Use only manufacturer approved PRD’’; and

g) Manufacturer date 08/98.

9.3 BIS Certification Marking

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.

9.4 Warning

Vehicles with Type 4 cylinder shall not be parked in enclosed space for extended periods of time. Permeation of gas through the cylinder wall or leakage between the end connections and the liner shall be considered in the design.

10 PRIOR TO DISPATCH

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. A corrosion inhibitor (for example oil-containing) shall be sprayed into all steel liners prior to dispatch.

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 in accordance with **5.2.3**.Guidance on the content of the instructions is given in Annex F.

ANNEX A

(*Clauses* 5.1, 6.3.6, 6.4.5, 6.5.2.2 to 6.5.2.14, 6.6.2.1, 6.6.2.2, 6.7, 7.3.6, 7.5.2.2 to 7.5.2.15, 7.6.2.1 to 7.6.2.3, 7.7, 7.7.1, 8.3.5, 8.4.4, 8.5.2.2 to 8.5.2.17, 8.6.2.1, 8.6.2.3 *and* 8.7)

TEST METHODS AND CRITERIA

A-1 TENSILE TESTS FOR STEEL AND ALUMINIUM LINERS

A tensile test shall be carried out on material taken from the cylindrical part of the finished liner using a rectangular test piece shaped in accordance with the method described in IS 15490 for steel and IS 15660 for aluminum. The two faces of the test piece representing the inside and outside surfaces of the liner shall not be machined. The tensile test shall be carried out in accordance with IS 1608 (Part 1).

The tensile strength shall meet the manufacturer's design specifications. The elongation of steel liner shall be at least 14 percent. The elongation of aluminium alloy liners for hoop wrapped construction shall be at least 12 percent. The elongation of aluminium alloy liners for full wrapped construction shall meet the manufacturer's design specifications.

A-2 IMPACT TEST FOR STEEL LINERS

The impact test shall be carried out on material taken from the cylindrical part of the liner on three test pieces in accordance with IS 1757 (Part 1).

The impact test pieces shall be taken in the direction as required in Table 9 from the wall of the cylinder. The notch shall be perpendicular to the face of the cylinder wall. For longitudinal tests, the test piece shall be machined all over (on six faces). If the wall thickness does not permit a final test piece width of 10 mm, the width shall be as near as practicable to the nominal thickness of the cylinder wall. Test pieces taken in the transverse direction shall be machined on four faces only, the inner and outer face of the cylinder wall shall be unmachined. The impact values shall be not less than those specified in Table 9.

A-3 SULPHIDE STRESS CRACKING TEST FOR STEEL

If the upper limit of the specified tensile strength for the steel exceeds 950 MPa, the steel from a finished, cylinder shall be subjected to a sulphide stress cracking resistance test.

Tests shall be conducted on a minimum of three tensile specimens with a gauge diameter of 3.81 mm machined from the wall of a liner. The specimens shall be placed under a constant tensile load equal to 60 percent of the specified minimum yield strength of the steel, immersed in a solution of distilled water buffered with 0.5 percent (mass fraction) sodium acetate trihydrate and adjusted to an initial *p*H of 4.0 using acetic acid. The solution shall be continuously saturated at room temperature and pressure with 0.414 kPa hydrogen sulphide (balance nitrogen). The tested specimens shall not fail within test duration of 144 h. Specimen that fails outside gauge are considered as invalid test.

NOTES

1 This is a test for type of material, duly heat treated, and results can be used for any cylinders from that material with same heat treatment.

2 For guidance method A – NACE Standard tensile test procedure as described in NACE standard TM0177-96 may be referred.

A-4 CORROSION TESTS FOR ALUMINIUM

Corrosion tests for aluminium alloy shall be carried out in accordance with the procedure given in **A-4.1** and **A-4.2** and meets the requirements given therein.

A-4.1 Tests for Assessing Susceptibility to Inter-crystalline Corrosion

A-4.1.1 *Principle*

The method described below consists of simultaneously immersing the specimen taken from the finished cylinder liner under test in a corrosive solution and examining them after a specified etching time in order to detect any signs of inter crystalline corrosion and determine the nature and degree of such corrosion. The propagation of inter crystalline corrosion is determined metallographically on polished surfaces cut transversally to the etched surface.

A-4.1.2 *Specimen Size*

Specimens are taken from the head, body and base of the cylinder (*see* Fig. 1). Each specimen shall be of the general shape and the dimensions indicated in Fig. 2.

The faces a_1-a_2-a_3-a_4, b_1-b_2-b_3-b_4, a_1-a_2-b_2-b_1 and a_4-a_3-b_3-b_4 are all cut with a band saw and then carefully trimmed with a fine file. The surfaces a-${}_1a_4$-b_4-b_1 and a_2-a_3-b_3-b_2 which correspond respectively to the inner and outer faces of the cylinder liner are left in their rough state.

Table 9 Impact Test Acceptance Values

(*Clause* A-2)

Sl No.	Cylinder Diameter *D*, in mm		> 140			≤ 140
(1)	(2)		(3)			(4)
i)	Direction of testing			Transverse		Longitudinal
ii)	Width of Test Piece, mm		3-5	> 5-7.5	> 7.5-10	3-10
iii)	Test temperature, in °C			–50		–50
iv)	Impact strength in J/cm^2,	Mean of 3 specimens	30	35	40	60
		Individual specimen	24	28	32	48

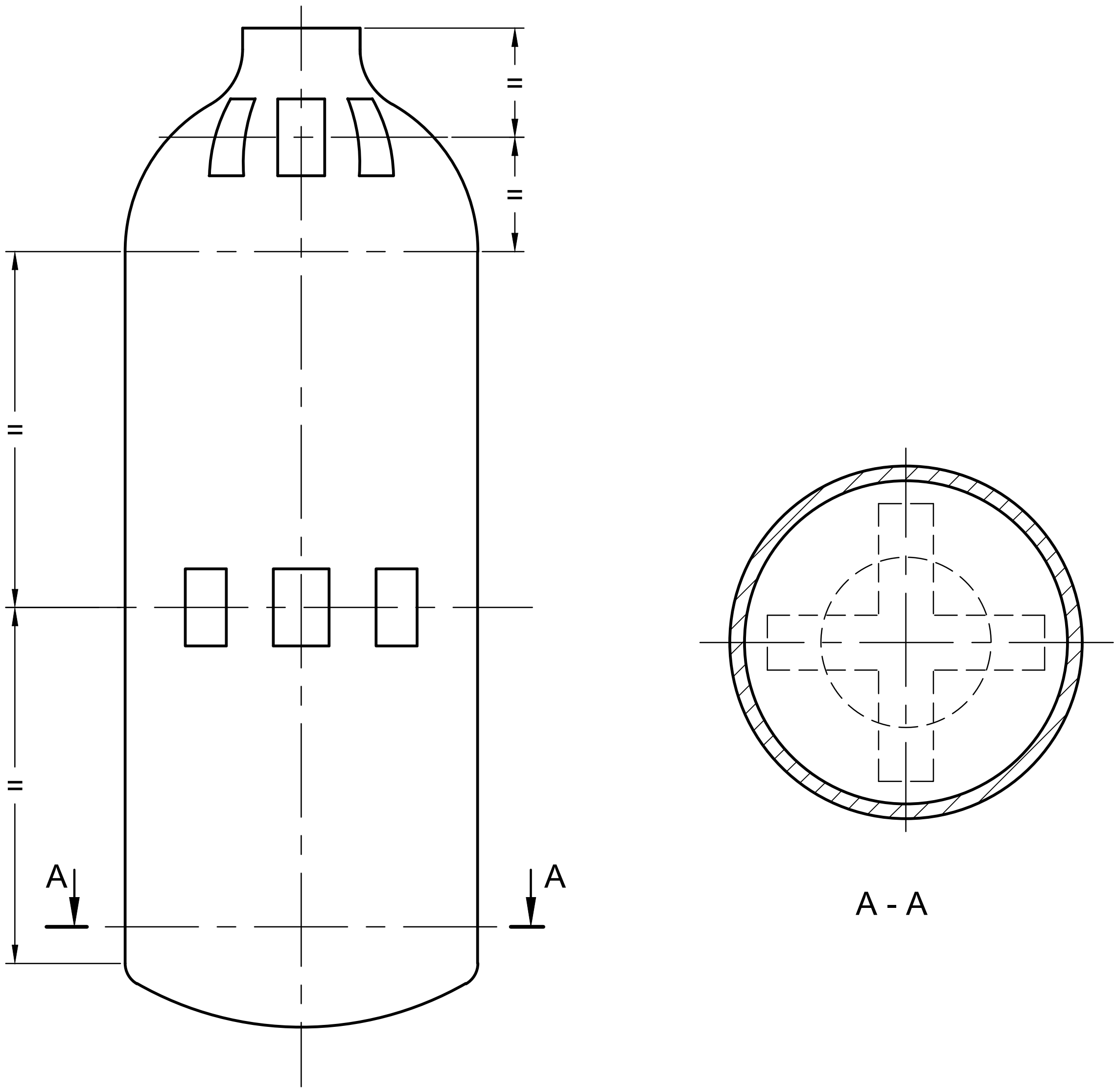
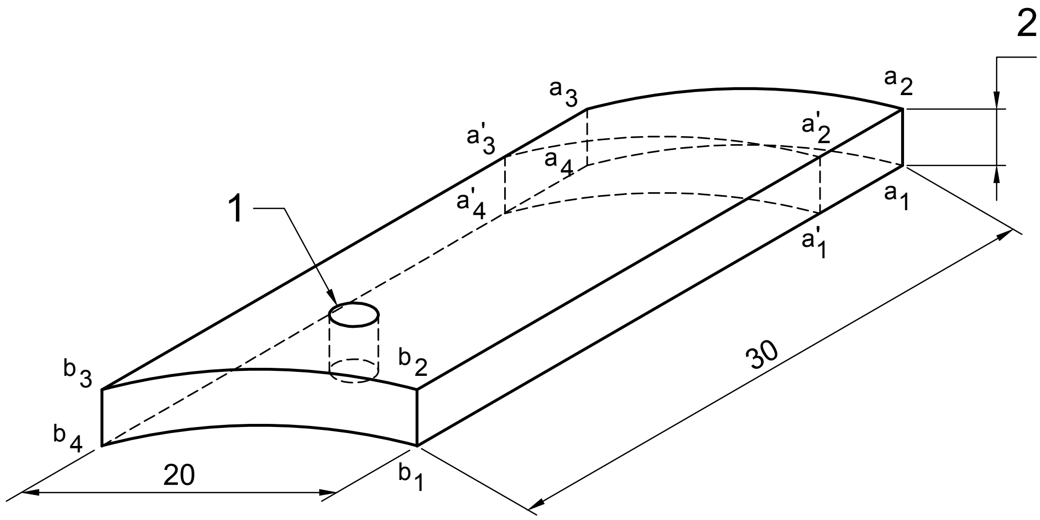


Fig. 1 Location of Specimens



KEY

1) HOLE Ø 3

2) THICKNESS OF THE CYLINDER

All dimensions in millimetres

FIG. 2 SPECIMEN SHAPE AND DIMENSIONS

A-4.1.3 *Preparation of Specimen Surface before Corrosive Etching*

A-4.1.3.1 *Reagents* — *Nitric acid*, *HNO_3*, analytical grade, density 1.33 g/cm^3.

Hydroflouric acid, HF, analytical grade, density 1.14 g/cm^3 (at 40 percent) and De-ionized or distilled water.

A-4.1.3.2 Prepare the following solution in a beaker:

Nitric acid (HNO_3)	:	63 cm^3
Hydrogen fluoride (HF)	:	6 cm^3
Water (H_2O)	:	931 cm^3

a) Bring the solution to a temperature of 95 °C. Treat each specimen, suspended on a wire made of aluminium or another inert material, in this solution for 1 min.

b) Wash in running water and then in de-ionized or distilled water.

c) Immerse the specimen in nitric acid for 1 min at room temperature to remove any copper deposit, which may have formed.

d) Rinse in de-ionized or distilled water.

e) To prevent oxidation of specimens they should be plunged, as soon as they have been prepared, into the corrosion bath intended for them.

A-4.1.4 *Preparation of Corrosive Solution*

The corrosive solution to be used contains 57 g/l of sodium chloride and 3 g/l of hydrogen peroxide.

A-4.1.4.1 *Reagents*

a) Sodium chloride, NaCl, crystallized, analytical grade;

b) Hydrogen peroxide, H_2O_2, 100 to 110 volumes;

c) Potassium permanganate, $KMnO_4$; analytical grade;

d) Sulphuric acid, H_2SO_4, analytical grade, density1.83 g/cm3;

e) De-ionized or distilled water; and

f) Titration of hydrogen peroxide.

A-4.1.4.2 Since hydrogen peroxide is not very stable, it is essential to check its titre before use. To do this:

a) take 10 cm^3 of hydrogen peroxide using a pipette and dilute to 1 000 cm^3 (in a gauged flask) with de-ionized or distilled water, thus obtaining a hydrogen peroxide solution which will be called '*C*'. Using a pipette, place in a conical flask;

b) 10 cm^3 of hydrogen peroxide solution C; and

c) 2 cm^3 approximately of sulphuric acid.

A solution of permanganate at 1.859 g/l is used for the titration. The permanganate itself acts as an indicator.

The reaction of the permanganate on the hydrogen peroxide in a sulfuric medium is expressed as:

$$2\ KMnO_4 + 5\ H_2O_2 + 3\ H_2SO_4 \longrightarrow K_2SO_4 + 2\ MnSO_4 + 8\ H2O + 5O_2$$

Which gives the equivalence: 316 g $KMnO_4$ = 170 gH_2O_2

Therefore 1 g of pure hydrogen peroxide reacts with 1.859 g of potassium permanganate, hence the use of a 1.859 g/l solution of potassium permanganate, which saturates volume, 1 g/l of hydrogen peroxide. Since, the hydrogen peroxide was diluted 100 times to begin with, the 10 cm^3 of the test sample represents 0.1 cm^3 of the original hydrogen peroxide.

Multiplying by ten the number of cubic centimetres of potassium permanganate solution used for titration, the titre *T* of the original hydrogen peroxide in g/l is obtained.

Method for 10 litres Corrosive Solution Preparation:

Dissolve 570 g of sodium chloride in de-ionized or distilled water to obtain a total volume of about 9 litre. Add the quantity of hydrogen peroxide calculated below. Mix and then make up the volume to 10 litres with de-ionized or distilled water.

Calculate the volume of hydrogen peroxide to be put into the solution as follows:

Quantity of hydrogen peroxide required 30 g.

If the hydrogen peroxide contains '*T*' g of H_2O_2/litre, the volume required, expressed in cm^3 will be $100 \times 30/T$

A-4.1.5 *Etching Conditions*

The corrosive solution is placed in a crystallizer (or possibly a large beaker), itself placed in a water bath. The water bath is stirred with a magnetic stirrer and the temperature is regulated with a contact thermometer.

The specimen is either suspended in the corrosive solution by a wire made of aluminium (or other inert material) or placed in a solution so that it rests only on the corners, the second method being preferable. The etching time is 6 h and the temperature fixed at 30 ± 1 °C. Care shall be taken to ensure the quantity of reagent is at least 10 cm^3 per cm^2 of specimen surface.

After etching, the specimen is washed in water, immersed for about 30 s in 50 percent dilute nitric acid, washed again in water and dried using compressed air free of oil. A number of specimens may be etched at the same time provided that they are of the same type of alloy and that they are not in contact. The minimum quantity of reagent per unit of specimen surface area shall be adhered to.

A-4.1.6 *Preparation of Specimens for Examination*

Each specimen is placed vertically in a casting dish so that it rests on face a_1-a_2-a_3-a_4. The casting dish can be of external diameter 40 mm, height 27 mm, wall thickness 2.5 mm. Around it is poured a mixture of epoxy resin and hardener (or equivalent) in the appropriate proportion. The usual setting time is about 24 h.

A certain amount of material is removed from face a_1-a_2-a_3-a_4 preferably by lathe, so that the section a'_1-a'_2-a'_3-a'_4 when examined under the microscope, cannot show corrosion from a_1-a_2-a_3-a_4. The distance between faces a_1-a_2-a_3-a_4 and a'_1-a'_2-a'_3-a'_4 that is the thickness removed by the lathe, shall be at least 2 mm (*see* Fig. 2 and Fig. 3)

Alternatively, prepare a section by sawing through plane a'_1-a'_2-a'_3-a'_4 (*see* Fig. 2) to remove a specimen between 5 mm and 10 mm thick (that is such that the thickness from a_1, to a_1 is between 5 mm and 10 mm).

Mount this specimen in a thermosetting or thermoplastic mounting compound with face a'_1-a'_2-a'_3-a'_4 exposed to allow mechanical polishing. The section for examination is polished mechanically with abrasive paper, a diamond compound and/or magnesia polishing compound.

A-4.1.7 *Micrographic Examination of Specimens*

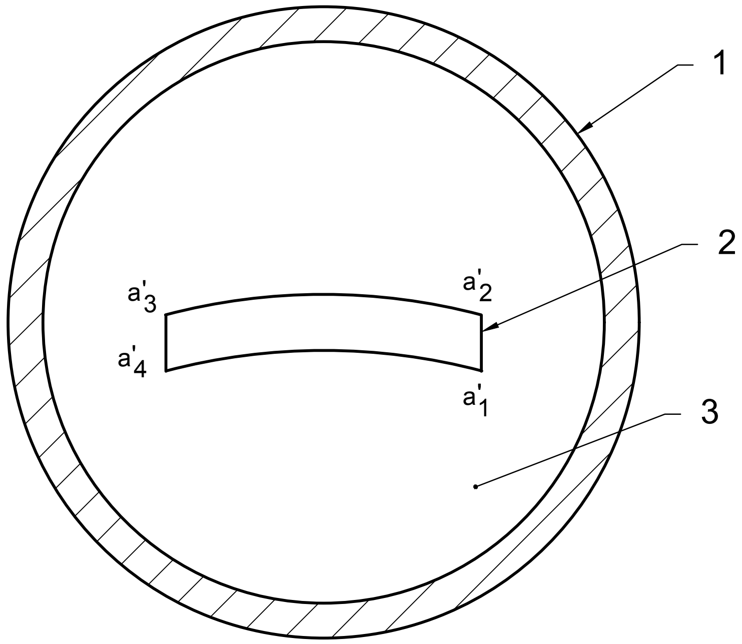
The examination is intended to assess the degree of penetration of inter-crystallization corrosion into each of the two faces, which make up the outer and inner surfaces of the cylinder.

The section is first examined at low magnification (for example X 40) in order to locate the most corroded areas, and then at a higher magnification, usually about X 300, in order to assess the nature and extent of the corrosion.

A-4.1.8 *Interpretation of Micrographic Examination*

a) For alloys with an equiaxed crystal structure the depth of corrosion shall not exceed the greater of the following two values:
   1) Three grains in the direction perpendicular to the face examined.
   2) 0.2 mm.

   But in no case shall the depth exceed 0.3 mm. However, it is permissible for these values to be exceeded locally provided that they are not exceeded in more than four fields of examination at X 300 magnification.
b) For alloys with a crystal structure oriented in one direction through cold working, the depth of corrosion into each of the two faces, which make up the internal and external surfaces of the cylinder, shall not exceed 0.1 mm.



KEY

1) CASTING MOULD
2) TEST PIECE
3) EPOXY RESIN AND HARDENER

FIG. 3 SPECIMEN IN CASTING DISH

A-4.2 Tests for Assessing Susceptibility to Stress Corrosion

A-4.2.1 *Principle*

The method described below consists of the subjection to stress of rings cut from the cylindrical part of the cylinder, their immersion in brine for a specified period, followed by removal of the brine and exposure to the air for a longer period and repetition of this cycle for 30 days. If there are no cracks after the period of 30 days, the alloy can be considered suitable for the manufacture of gas cylinders.

A-4.2.2 *Tests Specimens*

Six rings with a width of four times the actual wall thickness or 25 mm, whichever is the greater, are cut from the cylindrical part of the cylinder (*see* Fig. 4).The specimens shall have a 60° cut-out and be subjected to stress by means of a threaded bolt and two nuts (*see* Fig. 5). Neither inner nor outer surfaces of the specimens shall be machined.

A-4.2.3 *Surface Preparation before Corrosion Test*

All traces of grease, oil and adhesive used with stress gauges shall be removed with a suitable solvent.

A-4.2.4 *Preparation of Corrosive Solution*

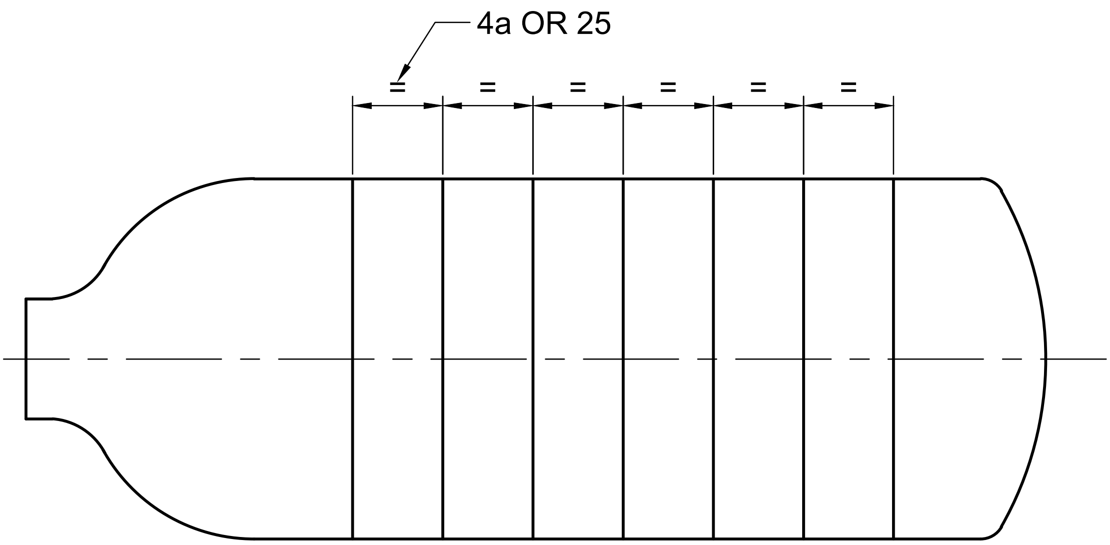
The brine is prepared by dissolving 3.5 parts ± 0.1 parts (*m*/*m*) of sodium chloride in 96.5 parts (*m*/*m*) of water.

The *p*H of the freshly prepare solution shall be in the range **6.4** to **7.2**. The *p*H may be corrected only by using dilute hydrochloric acid or dilute sodium hydroxide.

The solution shall not be topped up by adding the salt solution described, but only by adding distilled water up to the initial level in the vessel. Topping up maybe carried out daily if required. The solution shall be completely replaced every week.

A-4.2.5 *Applying Stress to Rings*

A-4.2.5.1 Three of the rings shall be compressed so that the outer surface is under tension. The other three rings shall be expanded so that the inner surface is under tension.



All dimensions in millimetres

FIG. 4 SPECIMEN RING LOCATION

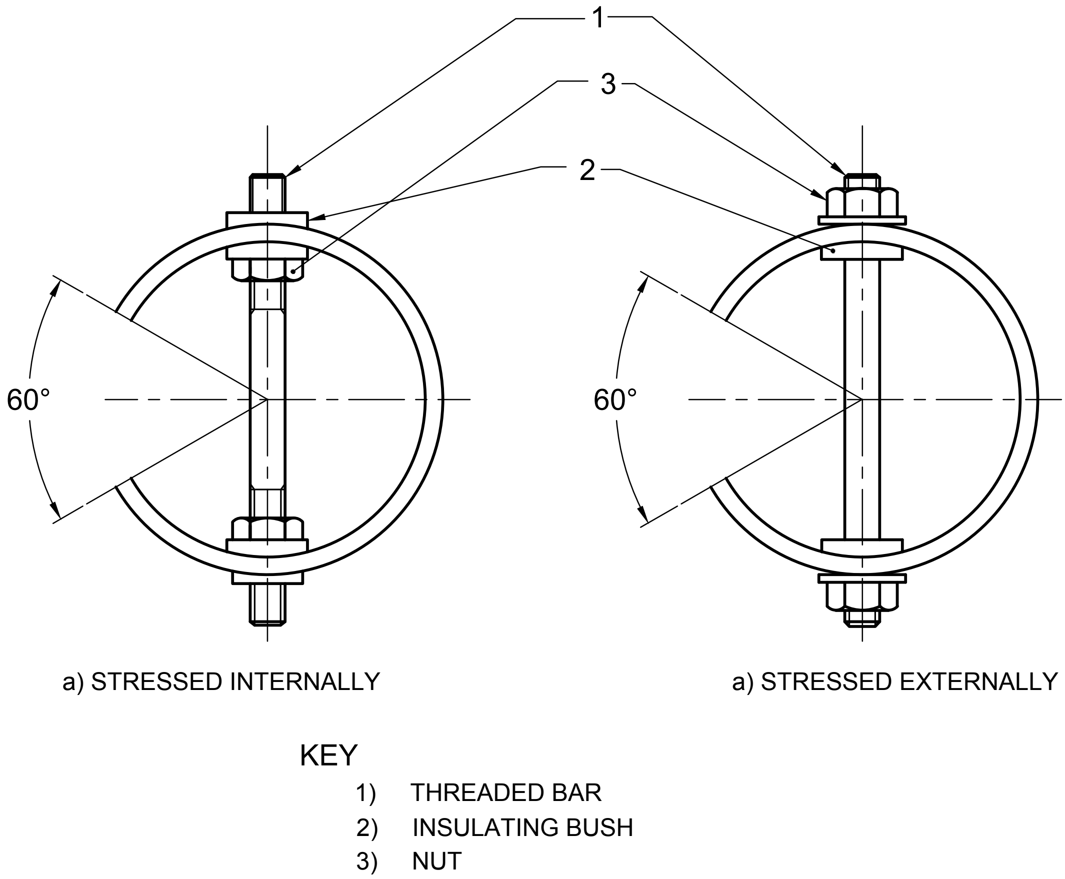


FIG. 5 STRESSED SPECIMENS

A-4.2.5.2 The rings shall be stressed to a maximum as given by:

$$R_e F$$

where

R_e = guaranteed minimum yield stress in MPa; and

F = design stress factor (variable).

A-4.2.5.3 The actual stress may be measured by electric stress gauges.

A-4.2.5.4 The diameter of the ring to achieve the required stress may be calculated using the following equation:

$$D' = D - [\prod R (D - t)^2]/(4 E t^2)$$

where

D' = diameter of the ring when compressed (or expanded), in mm;

D = outside diameter of the cylinder, in mm;

t = cylinder wall thickness, in mm;

E = modulus of elasticity in MPa = 70 000 MPa approximately;

Z = correction factor (*see* Fig. 6); and

R = (F. R_e), in MPa.

A-4.2.5.5 It is essential for the nuts and bolts be electrically insulated from the rings and protected from corrosion by the solution. The six rings shall be completely immersed in the salt solution for 10 min. They are then removed from the solution and exposed to the air for 50 min. This cycle shall be repeated for 30 days or until a ring break, whichever happens first. The specimens shall be visually inspected for any cracks.

A-4.2.6 *Interpretation of Results*

The alloys shall be considered acceptable for the manufacture of gas cylinder if none of the rings subjected to stress develops any cracks visible to the naked eye or visible at low-magnification (X 10 to X 30), at the end of the 30 day test period.

A-4.2.7 *Possible Metallographic Examination*

In the event of doubt about the presence of cracks (for example line of pitting), uncertainty may be removed by means of an additional metallographic examination of a section taken perpendicular to the axis of the rings in the suspect area. A comparison is made of the form (inter-or trans-crystalline) and depth of penetration the corrosion on the faces of the ring subjected to tensile and compressive stress.

The alloys shall be considered accepted if the corrosion on each face of the ring is similar. If, however, the face of the ring under tension reveals inter-crystalline cracks which are clearly deeper than those in the face under compression, the ring shall be considered to have failed the test.

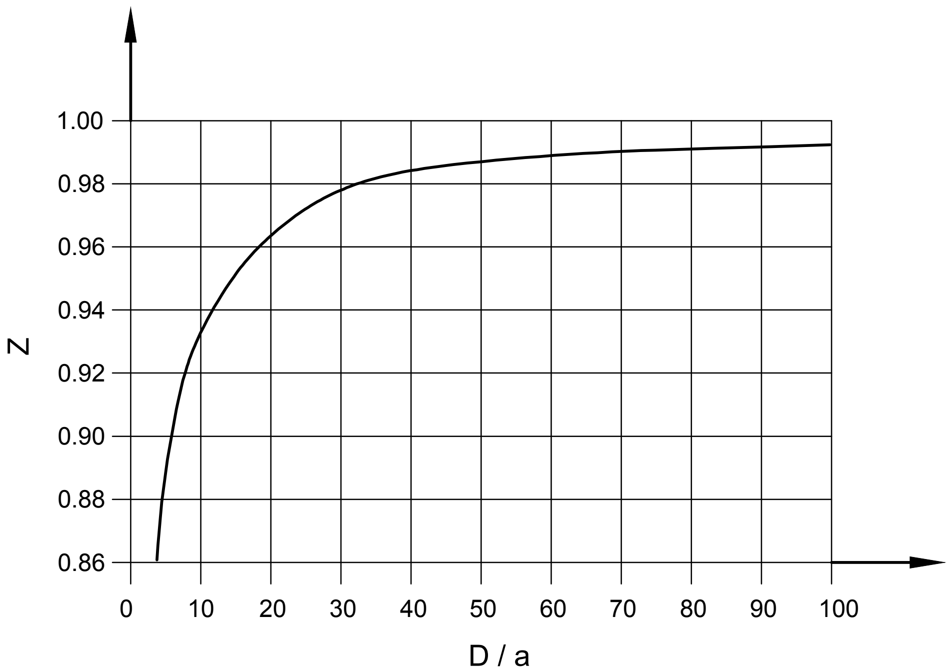


Fig. 6 Correction Factor Z Plotted Against D/a

A-5 SUSTAINED LOAD CRACKING (SLC) TESTS FOR ALUMINIUM

A-5.1 Principle

A fatigue pre-cracked specimen is loaded by a constant load or constant displacement method to stress intensity K_{IAPP} equal to a defined value. The specimen is kept in the loaded condition for a specified time and temperature. After the test period, the specimen is examined to assess whether the initial fatigue crack did or did not grow.

K_{IAPP} = applied elastic stress-intensity, in MPa√m;

V = crack-mouth opening displacement (CMOD), in mm, defined as the mode 1 (also called opening mode) component of crack displacement due to elastic and plastic deformation, measured at the location on a crack surface that has the greatest elastic displacement per unit load;

R_{eSLC} = average of measured yield stress of two specimens from the test cylinder representing the SLC test specimens location at room temperature, in MPa;

r = notch radius;

K_t = theoretical elastic stress concentration factor;

$K_{t'}$ = apparent crack tip stress intensity factor calculated on the basis of the notch depth and applied load;

M = bending moment;

μ = Poisson's ratio;

SLC = Sustained load cracking; and

K_{ISCC} = threshold stress intensity factor for susceptibility to stress corrosion cracking.

Liners with nominal neck and shoulder wall thickness ≤ 7 mm are exempt from the sustained load cracking tests. The inspector shall ensure that the neck/shoulder wall thickness of the actual cylinders reasonably represents the quoted nominal figure. Figure 7 illustrates the neck and shoulder thickness.

A-5.2 Specimen Configurations and Number of Tests

A-5.2.1 Any one or a combination of specimen geometries of the following listed specimens shall be used for the tests:

a) Compact tension test (CTS) specimen, *see* Fig. 8;
b) Double cantilever beam (DCB) specimen, *see* Fig. 9;
c) T-type wedge opening loaded (T-WOL) specimen, *see* Fig. 10; and
d) C shaped specimen, *see* Fig. 11

A-5.2.2 Specimen orientation shall be *Y-X* or *Y-Z* as shown in Fig. 12.

A-5.2.3 At least three specimens from the cylinder wall and if possible three specimens from the shoulder and three from the neck shall be tested. At each location, three specimens shall be taken as close to each other as possible. One specimen from each location shall be used for SLC testing and two from each location for tensile testing.

A-5.2.4 Flattening of specimen blanks is not allowed.

A-5.2.5 If test specimen thickness cannot be obtained from the specified location or locations to meet the validity requirements given below, then the thickest possible specimen shall be tested. The specimen shall be taken when the mechanical properties have been fully developed in the cylinder but before any external machining of the neck/shoulder area. Validity requirement for the specimen is given as:

$$A, B, B_n, (W-a) \geq 1.27\,(K_{IAPP}/R_{eSLC})^2 \times 1000$$

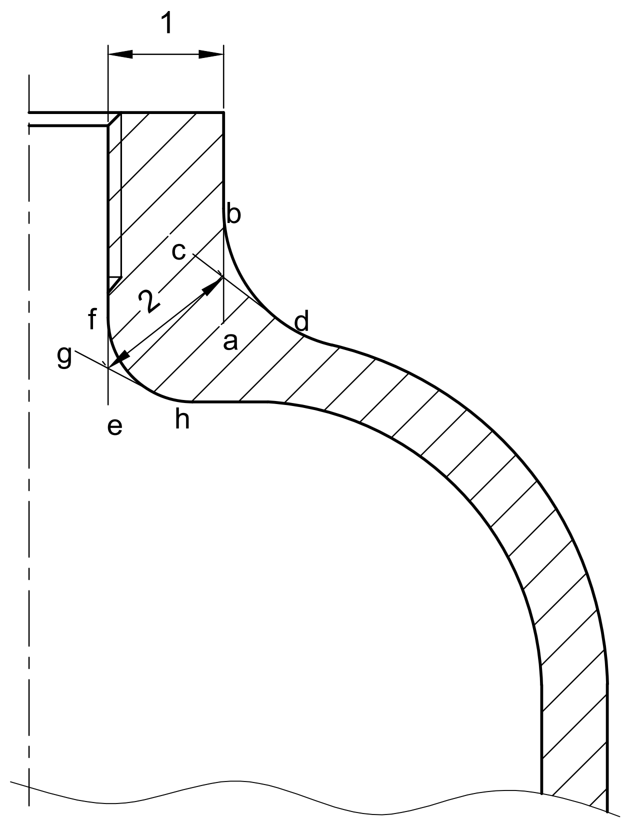
The notations are as indicated in the specimen sketches given Fig. 8 to Fig. 11. B_n refers the reduced thickness at side groove (minimum side-side dimension between the notches in side grooved specimens).

A-5.2.6 When it is impossible to obtain full size tensile specimens, small size specimens are permitted for determination of yield stress.

A-5.3 Fatigue Pre-cracking

A-5.3.1 The machine used for fatigue cracking shall have a means of loading such that the stress distribution is symmetrical about the notch and the applied load shall be known to an accuracy of ± 2.5 percent.

A-5.3.2 The environmental conditions apparent during fatigue pre-cracking, as well as the stressing conditions, can influence the subsequent behaviour of the specimen during stress corrosion testing. In some materials, the introduction of the stress corrosion test environment during the pre-cracking operation will promote a change from the normal ductile trans-granular mode of fatigue cracking to one that more closely resembles stress corrosion cracking. This may facilitate the subsequent initiation of stress corrosion cracking and lead to the determination of conservation initiation values of K_{ISCC}. However, unless facilities are available to commence stress corrosion testing immediately following the pre-cracking operation, corrodent remaining at the crack top may promote blunting due to corrosive attack. Furthermore, the reproducibility of results may suffer when pre-cracking is conducted in the presence of an aggressive environment because of the greater sensitivity of the corrosion fatigue fracture mode to the cyclic loading conditions. In addition, more elaborate facilities may be needed for environmental control purposes during pre-cracking. For these reasons, it is recommended that, unless agreed otherwise between the parties, fatigue pre-cracking shall be conducted in the normal laboratory air environment.



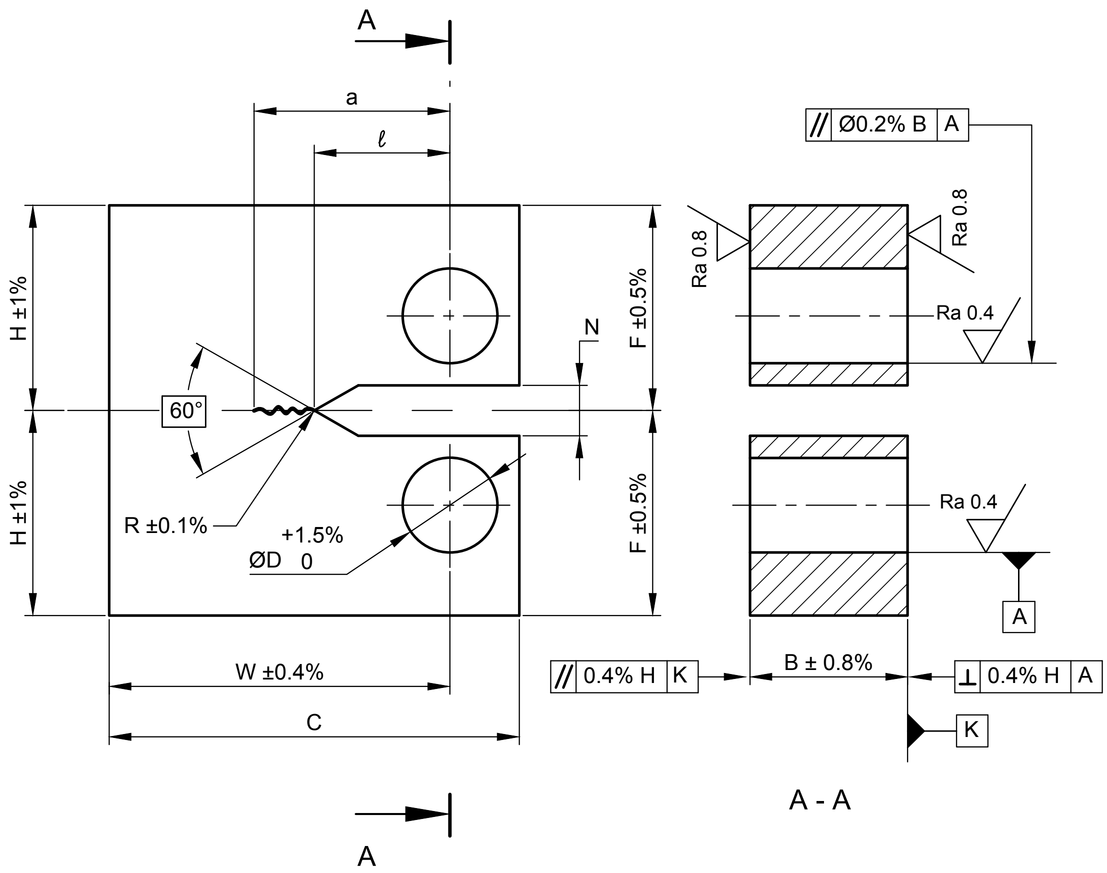
KEY

1) NOMINAL NECK THICKNESS
2) NOMINAL SHOULDER THICKNESS

NOTE :-

a-b, c-d, e-f AND g-h ARE TANGENTS INITIATING AT INTERSECTING SURFACES

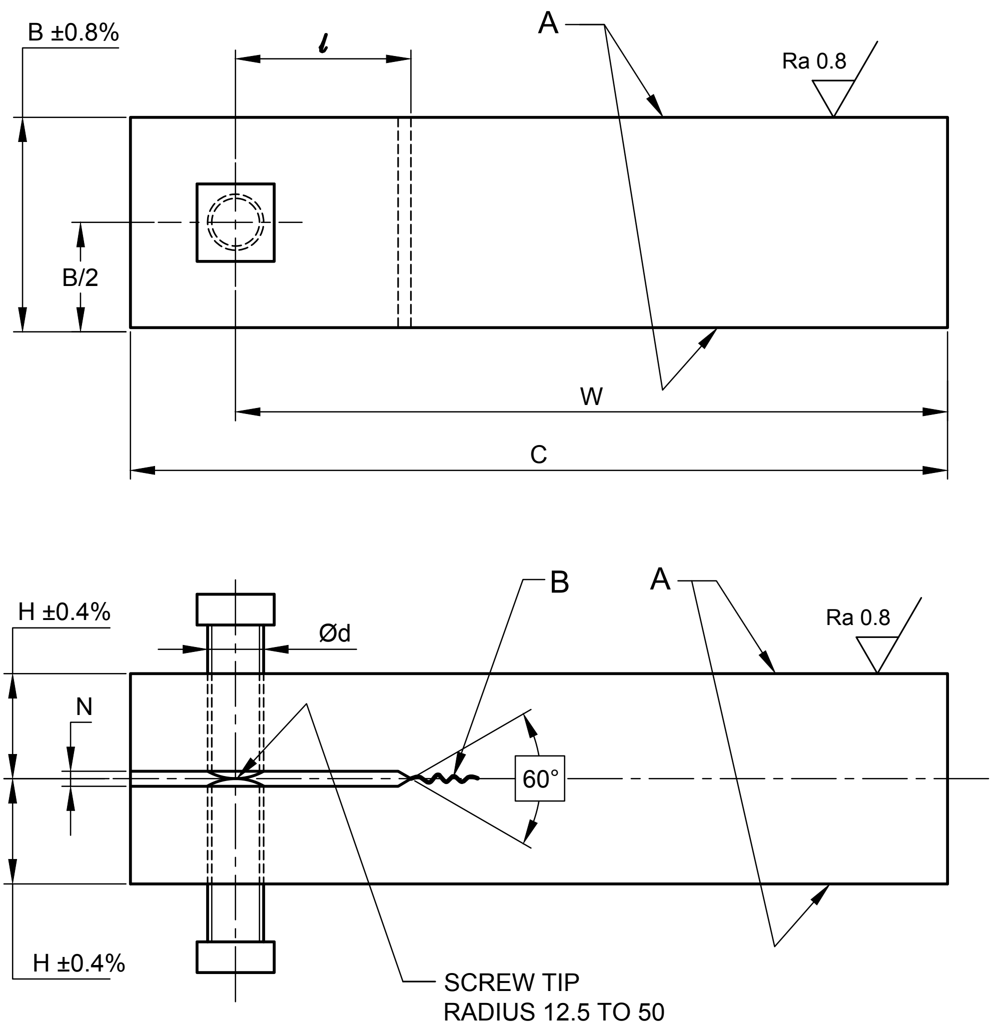
FIG. 7 ILLUSTRATION OF NECK AND SHOULDER THICKNESS



Net width	= W
Total width, C	= 1.25 W min.
Thickness, B	= 0.5 W
Half height, H	= 0.6 W
Hole diameter, D	= 0.25 W
Half distance between hole outer edges ,F	= 1.6 D
Notch width, N	= 0.065 W max.
Effective notch, length, ℓ	= 0.25 W TO 0.40 W
Effective crack, length, a	= 0.45 W TO 0.55 W

All dimensions in millimetres

FIG. 8 PROPORTIONAL DIMENSIONS AND TOLERANCES FOR COMPACT TENSILE TEST PIECE



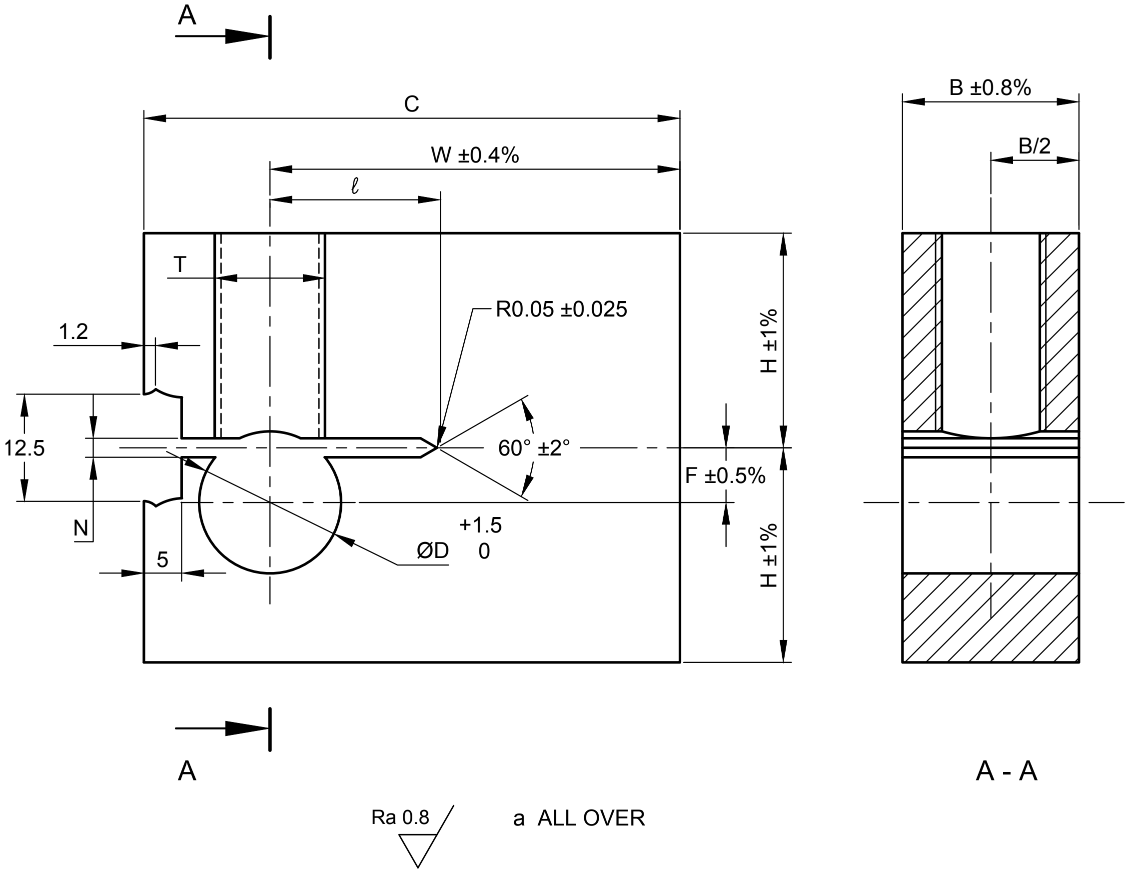
Half height	= H
Thickness, B	= 2H
Net width, W	= 10 H min.
Total width, C	= W + d
Screw diameter, d	= 0.75 H min.
Notch width, N	= 0.14 H max.
Effective notch, length, ℓ	= 2 H

Note :-

1) "A" surfaces should be perpendicular and parallel as aplicable to within 0.002 h TIR
2) At each side point "b" should be equidistant from the top to bottom surface to within 0.001 h
3) The bolt centreline should be normal to the specimen centreline to within 1°
4) The bolt material should be similar to that of the specimen, fine threaded with a square or allen - screw head
5) Surface roughness values in microns

All dimensions in millimetres

FIG. 9 PROPORTIONAL DIMENSIONS AND TOLERANCES FOR DOUBLE CANTILEVER BEAM TEST PIECES



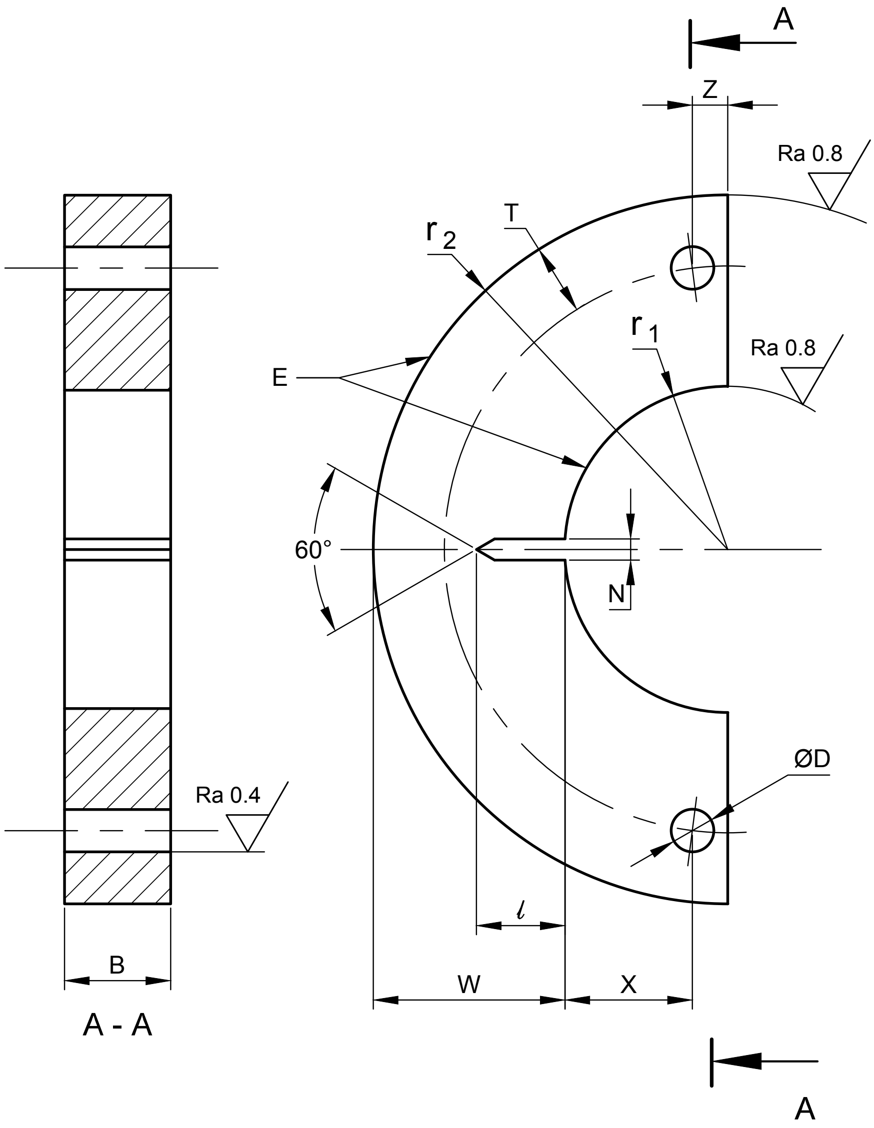
Thickness	= B
Net width, W	= 2.55 B
Total width, C	= 3.20 B
Half height, H	= 1.24 B
Hole diameter, D	= 0.718 B ± 0.003 B
Effective notch, Length, ℓ	= 0.77 B
Notch width, N	= 0.06 B
Thread diameter, T	= 0.625 B
Distance from hole centreline to notch centreline, F	= 0.239 B

Notes :-

1) Surface should be perpendicular and parrallel as applicable to within 0.002 *H* TIR
2) The bolt centreline should be normal to the specimen centreline to within 1°
3) The bolt material should be similar to that of the specimen, fine-threaded with a square or allen scew head
4) Surface roughness values in microns

All dimensions in millimetres

Fig. 10 Proportional Dimensions and Tolerance for Modified Wedge Opening Loaded Test Pieces



Net width	= W
Thickness, B	= 0.5 W ±0.01 W
Distance from hole axes to tangent with the inner surface, X Notch width, N	= 0.50 W ±0.005 W = 1.5 min. (0.1 W max.)
Notch length, ℓ	= 0.3 W
Distance from the hole axes to face of the specimen, Z	= 0.25 W ±0.01 W
Distance from the hole axes to outer surface,T	= 0.25 W ±0.01 W
Diameter of holes, D	= 0.25 W ±0.005 W

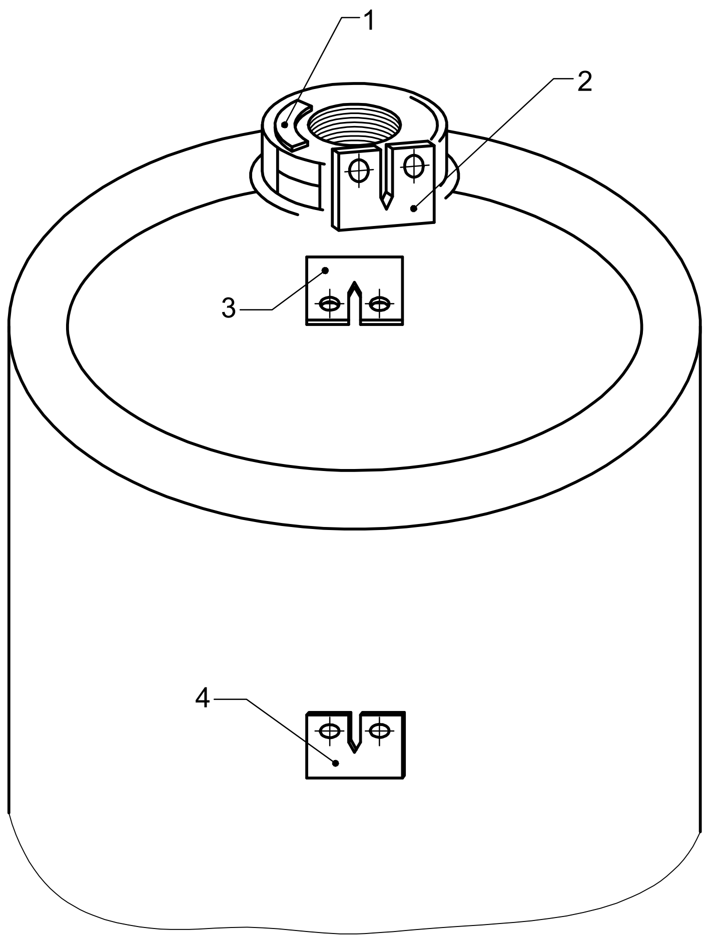
Note

1) All surface should be perpendicular and parrallel as applicable to within 0.002 W TIR and "E" surfaces should be perpendicular to "Y" surfaces to within 0.02 W TIR

2) Surface roughness values in microns

All dimensions in millimetres

Fig. 11 Proportional Dimensions and Tolerances for C-Shaped Test Pieces



key

1) Neck specimen Y - Z
2) Neck specimen Y - X
3) Shoulder specimen Y - Z
4) Cylinder wall specimen Y - X

Note :-

1) Specimen should be taken as close as possible to neck.
2) Notch direction shall be toward the neck, as shown

FIG. 12 ORIENTATION OF NECK, SHOULDER AND CYLINDER WALL SPECIMENS

A-5.3.3 The specimens shall be pre-cracked by fatigue loading with an R value in the range 0 to 0.1 until the crack extends at least 2.5 percent W or 1.25 mm beyond the notch at the side surfaces, whichever is greater.

A-5.3.4 The final length of the fatigue crack shall be such that the requirement for plane strain predominance is satisfied by the following equation:

$$a > 1.27\ (K_{IAPP}/R_{eSLC})^2 \times 1000$$

A-5.4 Specimen Testing Procedure

A-5.4.1 Before testing, the thickness B and either width W or half-height H [in the case of ($W–a$) in different specimens] shall be measured to within 0.1 percent W (or H) from the crack plane.

A-5.4.2 Load the fatigue pre-cracked specimens to a stress-intensity KIAPP determined from the following equation:

$$K_{IAPP} = 0.056\ R_{eSLC}$$

Specimens shall be loaded by a suitable constant displacement or constant load method.

A-5.4.3 For specimens loaded by a constant displacement method, the loading shall be either the non-monitored load method or the monitored load method and shall meet the following requirements.

a) For non-monitored load method:
   1) Record the crack mouth opening displacement (CMOD) at the end of the test, before unloading;
   2) Unload the specimen; and
   3) Reload the specimen up to the measured CMOD in a device suitable for load measurement, Record the load and use this load in the K_{IAPP} calculations. This calculated K_{IAPP} shall be equal to or greater than the calculated K_{IAPP} value from **A-5.4.2.**

b) For monitored load method:
   1) The final load at the end of the test period shall be applied in the K_{IAPP} calculations; and
   2) This calculated KIAPP shall be equal to or greater than the calculated KIAPP value from **A-5.4.2.**

A-5.4.4 *Testing Using the Constant Displacement Method*

a) For testing of compact tension specimen (CTS) specimens at a constant displacement loading, use the following equations to determine V:

$$V = \frac{K_{IAPP}\left(\sqrt{W}\right)}{(0.032)(E)(f(x))\left(\sqrt{BIB_N}\right)}$$

$$(x) = \frac{2.24\left(1.72 - 0.9x + x^2\right)\left(\sqrt{1-x}\right)}{\left(9.85 - 0.17x + 11x^2\right)}$$

$$x = a/w$$

b) For testing of C-shaped specimens at a constant displacement loading, use the following equations:

For specimens with $X/W = 0$

$$P_2 = (2 + a/w)/(1 - a/w)^2\ ;$$

$$Q_2 = 0.399 + 12.63\,(a/w) - 9.838(a/w)^2 + 4.66(a/w)^3$$

$$V = \frac{(K_{IAPP})\left(\sqrt{W}\right)(P_1)\left[0.43(1 - r_1/r_2 + Q_1)\right]}{(0.032)(E)(Y)}$$

For specimens with X/W = 0.5

$$V = \frac{(K_{IAPP})\left(\sqrt{W}\right)(P_2)\left[0.45(1 - r_1/r_2 + Q_2)\right]}{(0.032)(E)(Y)}$$

where

$Y = [18.23\ \sqrt{(a/W)} - 106.2\ \sqrt{(a^2/W)} + 397.7\ \sqrt{(a^5/W)} - 582.0 - \sqrt{(a^2/W)}\ 369.1\ \sqrt{(a^2/W)}] \times [1+1.54\ (X/W) + 0.5\ (a/W)]\ [1 + 0.22\ (1 - \sqrt{(a/W)}\ (1 - r_1/r_2)]$

$P_1 = (1 + a/W)/(1 - a/W)^2$

$Q_1 = 0.542 + 13.137\ (a/W) - 12.316\ (a/W)^2 + 6.576\ (a/W)^3$

$P_2 = (2 + a/W)/(1 - a/W)^2$

$Q_2 = 0.399 + 12.63\ (a/W) - 9.838\ (a/W)^2 + 4.66\ (a/W)^3$

c) The stress intensity factor equations for DC Band T-WOL specimens are:

The stress intensity factor equations for double cantilever beam specimen (DCB).

$$K_1 = \frac{E \times V_{yLL}\ H\sqrt{3H(a + 0.6H)^2 + H^3}}{4\left[(a + 0.6H)^3 + H^2 a\right]}$$

The stress intensity factor equations for wedge opening loaded specimen (WOL).

$$K_1 = \frac{YP}{B\sqrt{a}}$$

where

$$Y = 30.96\left(\frac{a}{W}\right) - 195.8\left(\frac{a}{W}\right)^2 + 730.6\left(\frac{a}{W}\right)^3 + 1\,186.3\left(\frac{a}{W}\right)^4 + 754.6\left(\frac{a}{W}\right)^5$$

advances by at least one millimeter. After fatigue cracking, break open the specimen.

A-5.4.5 *Testing Using the Constant Loading Method*

a) For testing DCB specimens at a constant load (P), the following equation shall be used:

KIAPP = (Pa/BH3/2) × (3.46 + 2.38 H/a)

The above equation shall satisfy the following validity requirements.

$2 \leq a/H \leq 10$

W/a + 2 H

b) For testing of CTS, T-WOL and C shaped specimens at a constant load, the stress intensity factor equations given in the previous section (*see* **5.4.4**) shall be used.

A-5.4.6 The loaded specimens shall be tested for 90 days at room temperature.

A.5.4.7 If the additional test referred to in **A-5.5.4** is required then repeat the entire procedure using only constant load conditions for a period of 180 days at room temperature.

A-5.5 Crack Growth Examination

A-5.5.1 After the specified test period, unload the specimen, fatigue the specimen at maximum stress intensity not exceeding 0.6 KIAPP till the crack.

A-5.5.2 Measure the distance between the two pre and post-fatigue cracks using a scanning electron microscope (SEM). Measurements shall be taken perpendicular to the pre- and post-fatigue cracks at 25 percent B, 50 percent B and 75 percent B locations. Calculate the average of these three values.

A-5.5.3 If the average measured distance between the two fatigues cracks does not exceed 0.16 mm, the specimen passes the test. If all the specimens pass, the alloy is qualified.

A-5.5.4 If the average measured values exceed 0.16 mm, the alloy may be qualified if, when subjected to the test described in **A-5.4.3**, the average measured distance between the two fatigue cracks does not exceed 0.3 mm. **A-5.5.1** and **A-5.5.2** shall also apply.

A-5.6 Interpretation of Results

If the test specimen exhibits less than or equal to a specified amount of crack growth, then the material is characterized as suitable for gas cylinders with respect to the sustained-load-cracking resistance requirement. Following the initial qualification for resistance to sustained-load-cracking, this procedure shall only be repeated, if it applies any one of the following conditions:

a) It is manufactured in a different factory; or
b) It is manufactured by a different process such as:
   1) Cold or hot extrusion, from cast or extruded or rolled billet;
   2) Cold or hot extrusion followed by cold drawing from cast or extruded or rolled billet;
   3) Cupping, flow forming, spinning and cold drawing sheet or plate; and
   4) Open necking at both ends of an extruded or cold drawn tube.
c) It is manufactured from an alloy of different composition limits from that used in the original prototype tests; and
d) It is given a different heat treatment that is outside the temperature range of 20 °C and/or for times shorter than those used for the original type approval less 10 percent.

A-5.7 Cylinder Thickness Qualification

If the specimen validity requirements are not met, then the material is suitable up to a maximum thickness of the cylinder location from where the specimens were taken provided the specimens meet the other requirements of this test method. The material is suitable for all thicknesses if the specimens meet the validity requirements and the other requirements of this test method.

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

Three finished cylinders shall be pressure cycled between 20 bar and 300 bar at a rate not to exceed 10 cycles per minute in accordance with **A-12**. All cylinders shall either fail by leakage or exceed 45 000 pressure cycles.

A-7 EXTREME TEMPERATURE PRESSURE CYCLING

A-7.1 Finished cylinders, with the composite wrapping free of any protective coating, shall be cycle tested, as follows:

a) Condition for 48 h at zero pressure, 65 °C or higher and 95 percent or greater relative humidity. The intent of this requirement shall be deemed met by spraying with a fine spray or mist of water in a chamber held at 65 °C;

b) Hydrostatically pressurize for 500 cycles multiplied by the specified service life in year between 20 bar and 260 bar at 65 °C or higher, and 95 percent or greater relative humidity;
c) Condition the cylinder and fluid at –40 °C or lower as measured in the fluid and on the cylinder surface; and
d) Pressurize from 20 bar to 200 bar for 500 cycles multiplied by the specified service life in years at –40 °C or lower. Adequate recording instrumentation shall be provided to ensure the minimum temperature of the fluid is maintained during the low temperature cycling.

A-7.2 The pressure cycling rate of (b) shall not exceed shall not exceed 3 cycles per minute unless a pressure transducer is installed directly within the cylinder.

A-7.3 During this pressure cycling, the cylinder shall show no evidence of rupture, leakage or fibre unravelling.

A-7.4 Following pressure cycling at extreme temperatures, cylinder shall be hydrostatically pressured to failure in accordance with **A-11**, and achieve a minimum burst pressure of 85 percent of the minimum design burst pressure. For non-metal lined full wrapped designs, prior to the hydrostatic burst test, the cylinder shall be leak tested in accordance with **A-9**.

A-8 BRINELL HARDNESS TEST

Hardness test shall be carried out on the parallel wall of each liner in accordance with IS 1500 (Part 1) at the rate of one test per metre length of parallel wall. 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.

A-9 LEAK TEST FOR NON-METAL-LINED FULL WRAPPED CYLINDERS

A-9.1 Non-metal-lined full wrapped designs shall be leak tested using the following procedure (or an alternative acceptable to the inspector):

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

A-9.2 Any leakage detected shall be cause for rejection.

NOTE — Leakage is the release of gas through a crack, pore, un-bond or similar defect.

A-9.3 Permeation through the wall in compliance with **A-20** is not considered to be leakage.

A-10 HYDRAULIC TEST

Any internal pressure applied after Autofrettage and prior to the hydrostatic test shall not exceed 90 percent of the hydrostatic test pressure. One of the following two options shall be used.

A-10.1 Volumetric Expansion Test

a) 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.
b) Pressure shall be maintained for 30 s and 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.
c) Any cylinders not meeting the defined rejection limit shall be rejected and rendered unserviceable.

A-10.2 Proof Pressure Test

The hydrostatic pressure in the cylinder shall be increased gradually and regularly until the test pressure, at least 1.5 times working pressure is reached. The cylinder test pressure shall be maintained for at least 30 s to establish that there are no leaks.

A-11 HYDROSTATIC PRESSURE BURST TEST

The rate of pressurization shall not exceed 14 bar/s at pressures in excess of 80 percent of the design burst pressure. The rate of pressurization at pressures in excess of 80 percent of the design burst pressure exceeds 3.5 bar/s, then either the cylinder shall be placed schematically between the pressure source and the pressure measurement device, or there shall be a 5s hold at the minimum design burst pressure.

The minimum required (calculated) burst pressure shall be at least 450 bar, and in no case less than the value necessary to meet the stress ratio requirements. Actual burst pressure shall be recorded. Rupture may occur in either the cylindrical region or the dome region of the cylinder.

A-12 AMBIENT TEMPERATURE PRESSURE CYCLING TEST

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

a) Fill the cylinder to be tested with a noncorrosive fluid such as oil, inhibited water or glycol; and

b) Cycle the pressure in the cylinder between 20 bar and 260 bar at a rate not exceeding 10 cycles per minute.

The number of cycles to failure shall be reported, along with the location and description of the failure initiation.

A-13 ACID ENVIRONMENT TEST

A-13.1 Cylinder Set-up and Preparation

One cylinder shall be tested, including coating if applicable.

The upper section of the cylinder shall be divided into 5 distinct areas and marked for pendulum impact preconditioning and fluid exposure (*see* Fig. 13). The areas shall be nominally 100 mm in diameter. While convenient for testing, the areas need not be oriented along a single line, but shall not overlap.

Although preconditioning and fluid exposure is performed on the cylindrical portion of the cylinder, all of the cylinder, including the domed sections, shall be as resistant to the exposure environments as the tested areas.

A-13.2 Pendulum Impact Preconditioning

The impact body shall be of steel and 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 shall be 1 m. The total mass of the pendulum shall be such that the impact energy of the pendulum at the moment of impact is not less than 30 Nm and is as close to that value as possible.

During pendulum impact, the cylinder shall be held in position by the end bosses or by the intended mounting brackets. Each of the five areas identified in Fig. 13 shall be preconditioned by impact of the pendulum body summit at the centre of the area. The cylinder shall be un-pressurized during preconditioning.

A-13.3 Environmental Fluids for Exposure

Each marked area is to be exposed to one of five solutions. The five solutions are:

a) *Sulfuric Acid* — 19 percent solution by volume, in water;
b) *Sodium Hydroxide* — 25 percent solution by weight, in water;
c) *5 percent Methanol/95 Percent* Gasoline — Gasoline concentration of M5 fuel meeting the requirements of ASTM D4814;
d) *Ammonium Nitrate* — 28 percent by weight, in water; and
e) Windshield washer fluid (50 percent by volume solution of methyl alcohol and water).

When exposed, the test sample shall be oriented with the exposure area uppermost. A pad of glass wool approximately 0.5 mm thick and between 90 and 100 mm in diameter shall be placed on the exposure area. 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, and to ensure that the concentration of the fluid is not changed significantly during the duration of the test.

A-13.4 Pressure Cycle and Pressure Hold

The cylinder shall be hydraulically pressure cycled between less than or equal to 20 bar and 260 bar for a total of 3 000 cycles. The maximum pressurization rate shall be 27.5 bar per second. After pressure cycling, the cylinder shall be pressurized to 260 bar and held at that pressure a minimum of 24 h and until the elapsed exposure time (pressure cycling and pressure hold) to the environmental fluids equals 48 h.

A -13.5 Acceptable Result

The cylinder shall be burst tested in accordance with **A-12**, except that the burst pressure shall be no less than 1.8 times the working pressure.

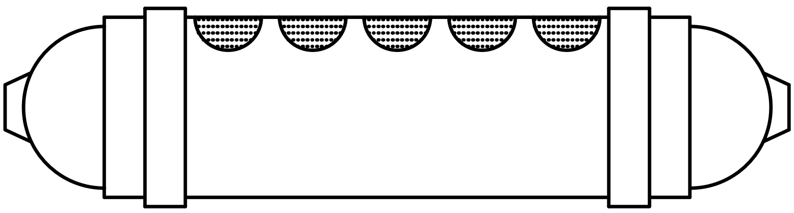


FIG.13 CYLINDER ORIENTATION AND LAYOUT OF EXPOSURE AREAS

A-14 BONFIRE TEST

A-14.1 General

The bonfire test is designed to demonstrate that finished cylinders, complete with the fire protection system (cylinder valve, pressure relief devices and/or integral thermal insulation) specified in the design, will prevent the rupture of the cylinder when tested under the specified fire conditions. Precautions shall be taken during fire testing in the event that cylinder rupture occurs. Provision shall be made to abandon the test any time during the test progress by providing a remotely placed bypass valve to release the pressure in the cylinder It should be ensured that if excess flow check valve is part of the valve, it is removed to make the bypass line operate without any obstruction.

A-14.2 Cylinder Set-up

The cylinder shall be placed horizontally with the cylinder bottom approximately 100 mm above the fire source.

Metallic shielding 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 specified fire protection system (pressure relief device or cylinder valve).

Any failure during the test of a valve, fitting or tubing that is not part of the intended protection system for the design shall invalidate the result.

A-14.3 Fire Source

A uniform fire source of 1.65 m length shall provide direct flame impingement on the cylinder surface across its entire diameter.

Any fuel may be used for the fire source provided it supplies uniform heat sufficient to maintain the specified test temperatures until the cylinder is vented. The selection of a fuel should take into consideration air pollution concerns. The arrangement of the fire shall be recorded in sufficient detail to ensure that the rate of heat input to the cylinder is reproducible.

Any failure or inconsistency of the fire source during a test shall invalidate the result.

A-14.4 Temperature and Pressure Measurements

Surface temperature shall be monitored by the least three thermocouples located along the bottom of the cylinder and spaced not more than 0.75 m apart.

Metallic shielding shall be used to prevent direct flame impingement on the thermocouples. Alternatively, thermocouples may be inserted into blocks of metal measuring less than 25 mm^2.

Thermocouple temperature and the cylinder pressure shall be recorded at intervals of every 30 s or less during the test.

A-14.5 General Test Requirements

A-14.5.1 The cylinder shall be pressurized to working pressure with natural gas or compressed air and tested in the horizontal position at working pressure and also at 25 percent of working pressure if a thermally activated PRD is not used.

NOTE — In case thermally activated PRD is not used, total 2 cylinders shall be subjected to bonfire test.

A-14.5.2 Immediately following ignition, the fire shall produce flame impingement on the surface of the cylinder along the 1.65 m length of the fire source and across the cylinder diameter.

A-14.5.3 Within 5 min of ignition, the temperature in at least one thermocouple shall indicate a temperature ≥ 590 °C. This minimum temperature shall be maintained for the remainder of the test.

A-14.5.4 If the temperature of 590 °C is not reached within 5 min but the cylinder vents within 5 min and the condition of **A-14.6** is fulfilled, the test shall be considered as acceptable.

A-14.5.5 For cylinders of length 1.65 m or less, the centre of the cylinder shall be positioned over the centre of the fire source.

A-14.5.6 For cylinders of length greater than 1.65 m, the cylinder shall be positioned as follows:

a) If the cylinder is fitted with a pressure relief device at one end, the fire source shall commence at the opposite end of the cylinder;
b) If the cylinder is fitted with a pressure relief device at both ends, or at more than one location along the length of the cylinder, the centre of the fire source shall be centered midway between the pressure relief devices that are separated by the greatest horizontal distance; and
c) If the cylinder is additionally protected using thermal insulation, then two fire tests at service pressure shall be performed, one with the fire centered midway along the cylinder length, and the other the fire commencing at one of the ends of a second cylinder.

A-14.6 Acceptable Results

The cylinder shall vent through a pressure relief device.

A-15 PENETRATION TEST

A cylinder pressurized to 200 ± 10 bar with compressed as shall be penetrated by an armour piercing bullet with a diameter of 7.62 mm or greater. The bullet shall completely penetrate at least one side wall of the cylinder. The projectile shall impact the sidewall at an approximate angle of 45°. The cylinder shall not rupture.

A-16 COMPOSITE FLAW TOLERANCE TESTS

One finished cylinder, complete with protective coating, shall have flaws cut into the composite in the longitudinal direction. The flaws shall be greater than visual inspection limits as specified by the manufacturer. As a minimum, one flaw shall be 25 mm long and 1.25 mm in depth and another flaw shall be 200 mm long and 0.75 mm in depth, cut in the longitudinal direction into the cylinder side wall.

The flawed cylinder shall then be pressure cycled between 20 bar and 260 bar at ambient temperature, initially for the design lifetime in years × 1 000 cycles.

The cylinder shall not leak or rupture within the first 3 000 cycles, but may fail by leakage during the further design lifetime in years × 1 000 cycles (less the 3 000 cycles already performed). All cylinders which complete this test shall be destroyed.

A-17 HIGH TEMPERATURE CREEP TEST

This test is required for designs in which the glass transition temperature of the resin matrix does not exceed 102 °C. One finished cylinder shall be tested as follows:

a) The cylinder shall be pressurized to 260 bar and held at a temperature of 100 °C for not less than 200 h; and
b) Following the test, the cylinder shall meet the requirements of the hydrostatic expansion test (*see* **A-10**), the leak test (*see* **A-9**) and the hydrostatic pressure burst test (*see* **A-11**).

A-18 ACCELERATED STRESS RUPTURE TEST

One cylinder shall be hydrostatically pressurized to 260 bar at 65 °C. The cylinder shall be held at this pressure and temperature for 1 000 h. The cylinder shall then be pressured to burst in accordance with the procedure described in **A-12**, except that the burst pressure shall exceed 85 percent of the minimum design burst pressure.

A-19 IMPACT DAMAGE TEST (DROP TEST)

One or more finished cylinders shall be drop tested at ambient temperature without internal pressurization or attached valves. The surface on to which the cylinders are dropped shall be a smooth, horizontal concrete pad or flooring. One cylinder shall be dropped in a horizontal position with the bottom 1.8 m above the surface on to which it is dropped. 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 1.8 m. One cylinder shall be dropped at a 45° angle on to a dome, from a height such that the center of gravity is at 1.8 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 center of gravity of 1.8 m.

The cylinder shall be allowed to bounce on the concrete pad or flooring after the initial impact. No attempt shall be made to prevent this secondary impacting, but the cylinder may be prevented from toppling during the vertical drop tests.

Following the drop impact, the cylinders shall then be pressure cycled between 20 bar and 260 bar at ambient temperature for the design lifetime in years × 1 000 cycles.

The cylinder shall not leak or rupture within the first 3 000 cycles, but may fail by leakage during the further design lifetime in years × 1 000 (less the 3 000 cycles already performed). All cylinders which complete this test shall be destroyed.

A-20 PERMEATION TEST

This test is required only for non-metal lined full wrapped cylinders. One finished cylinder shall be filled with compressed nature gas to working pressure, placed in an enclosed sealed chamber at ambient temperature, and monitored for leakage for 500 h. The permeation rate shall be less than 0.25 ml of natural gas per hour per litre water capacity of the cylinder. Examples of leakage measurement techniques include gas chromatography, mass spectrometry and weight loss.

A-21 TENSILE PROPERTIES OF PLASTICS

The tensile yield strength and ultimate elongation of plastic liner material shall be determined at – 50 °C. For the determination of tensile properties of plastics, the general testing principles given in Section 1 and 2 of IS 13360 (Part 5) may be referred. The test results shall demonstrate the ductile properties of the plastic liner material at temperatures of – 50 °C or lower by meeting the values specified by the manufacturer.

A-22 SOFTENING TEMPERATURE OF PLASTICS

Polymeric materials from finished liners shall be tested in accordance with a method described in IS 13360 (Part 6/Sec 1). The softening temperature shall be at least 100 °C.

A-23 BOSS TORQUE TEST

The body of the cylinder shall be restrained against rotation and a torque of twice the valve or *PRD* installation torque specified by the manufacturer shall be applied to each end boss of the cylinder. The torque shall be applied first in the direction of tightening at threaded connection, then in the un-tightening direction and finally again in the tightening direction. The cylinder shall then be subjected to a leak test in accordance with **A-9**.

A-24 COATING BATCH TESTS

A-24.1 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.

A-24.2 Coating Adhesion

The coating adhesion strength shall be measured in accordance with ASTM3359, using Method A or B as appropriate, and shall have a minimum rating of 4 when measured using either test Method A or B, as appropriate.

A-25 RESIN SHEAR STRENGTH

Resin material shall be tested on a sample coupon representative of the composite overwrap in accordance with the procedure given in this clause. Following 24 h boiling in water the composite shall have minimum shear strength of 13.8 MPa.

A-25.1 Principle

A bar of rectangular cross-section is loaded as a simple beam in flexure so that inter laminar shear failure occurs. The bar rests on two supports and the load is applied by means of a loading member midway between the supports.

The result obtained is not an absolute value. For this reason the term 'apparent inter-laminar shear strength' is used to define the quantity measured. Test results from different-sized specimens, or from specimens tested under different conditions, are not directly comparable.

A-25.2 Test Specimens

A-25.2.1 *Standard Test Specimens*

Test specimens shall comprise rectangular bars of uniform thickness:

Thickness (h)	: 2 ± 0.2 mm
Overall length (l)	: 20 ± 1 mm
Width (b)	: 10 ± 0.2 mm

A-25.2.2 *Other Test Specimens*

A-25.2.2.1 When it is not desirable to use the standard specimen, the following rules shall be observed:

a) The length and the thickness of the test specimen shall be in the same ratio as in the standard specimen, that is, length (l) = 10 h.
b) The width shall be chosen in the same ratio to the thickness as in the standard specimen, that is, width (b) = 5 h.

A-25.2.2.2 Depending upon the material being tested, specimens of 2 mm thickness may fail by shear or experience compression failure under load or exhibit extreme deflection without shear failure. As specimen thickness (height) is increased, the probability of compression failure under the load increases and the probability of extreme deflection with no failure decrease. As specimen thickness is decreased, the reverse is true. It is important to select a specimen thickness that will cause specimens to fail by horizontal shear.

A-25.3 Test Set-up

The width of the loading member and the supports shall be greater than the test specimen width (*see* Fig.14). The loading member shall apply the load mid-way between the supports. The span (distance between the supports) shall be adjustable. The load indicator shall be such that the error in the indicated loads is less than 61 percent of full scale. The radius of the loading member r_1 shall be 5 ± 0.2 mm and that of the supports r_2 shall be 2 ± 0.2 mm.

NOTE — Measure at the mid-point of each test specimen, the width b and the thickness h of the specimen to the nearest 0.02 mm using a micrometer or an equivalent.

A-25.4 Preparation of Specimens

Machine the test specimens from a moulded blank or sheet. The specimens shall be flat and free of twist. The surfaces and edges shall be free from defects. The thickness along the whole length shall be within ± 5 percent of the mean thickness. The width of individual specimens shall be constant to within 0.2 mm. Specimens showing measurable or observable departure from one or more of these requirements shall be rejected or machined to the required size and shape before testing.

A-25.5 Number of Test Specimens

At least five test specimens shall be tested. When the fiber orientation and distribution in the material to be tested does not differ significantly between the two principal directions, shear specimens shall be taken in each of these two directions. When the material has a preferred orientation, the specimens shall be taken in this direction (*see* Fig. 15).

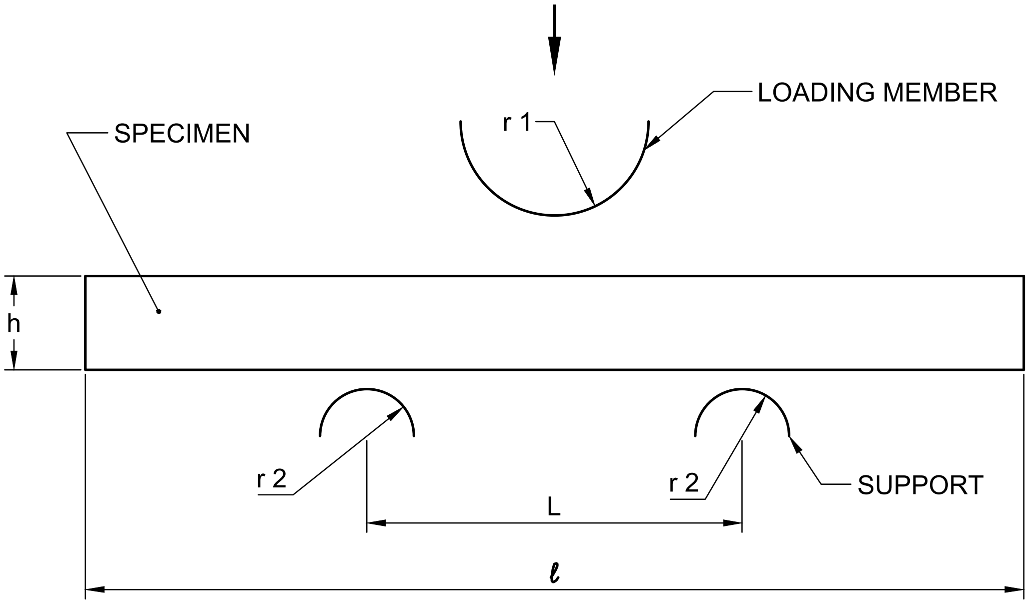


FIG. 14 LOADING CONFIGURATION

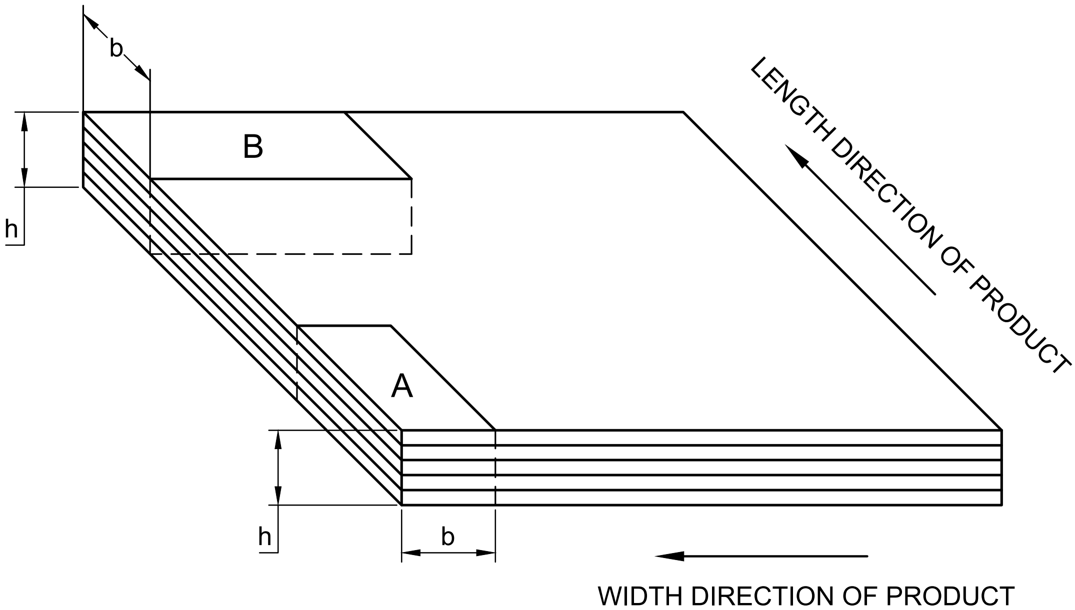


FIG. 15 LOCATIONS OF SPECIMEN

A-25.6 Procedure

Set the span L to 5 h ± 0.3 mm, where h is the mean thickness of the set of specimens. For some materials, a shorter span may be necessary to produce inter-laminar shear failure. Place the test specimen symmetrically across the two parallel supports with an un-machined surface in contact with the supports direction (*see* Fig. 16).

A-26 VALVE TORQUE TEST

A-26.1 The body of the cylinder shall be held to prevent it rotating. The cylinder shall be fitted with a corresponding valve and tightened to 150 percent of the maximum torque as recommended by the manufacturer. The parameters that shall be monitored and recorded are:

a) type of valve material;
b) valuing procedure; and
c) applied torque.

A-26.2 The cylinder neck or boss and threads shall remain within drawing and gauge tolerance.

A-27 NATURAL GAS CYCLING TEST

A-27.1 Special consideration shall be given to safety when conducting this test. Prior to conducting this test, cylinders of this design shall have successfully passed the test requirements of **A-9** (leak test), **A-11** (hydrostatic pressure burst test), **A-12** (ambient temperature pressure cycling test) and **A-20** (permeation test).

A-27.2 One finished type-4 cylinder shall be pressure cycled using compressed natural gas between less than 20 bar and working pressure for 1 000 cycles. The filling time shall be 5 min maximum. Unless otherwise specified by the manufacturer, care should be taken to ensure that temperatures during venting do not exceed the defined service conditions.

A-27.3 The cylinder shall be leak tested in accordance with **A-9** and meet the requirements therein. Following the completion of the natural gas cycling the cylinder shall be sectioned and the liner and liner/end boss interface inspected for evidence of any deterioration, such as fatigue cracking or electrostatic discharge.

SINGLE SHEAR MULTIPLE SHEAR

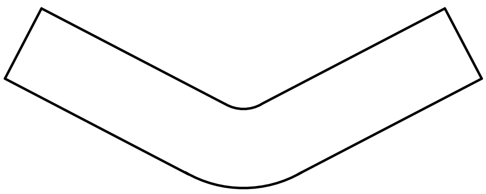
16A) SHEAR MODES OF FAILURE - ACCEPTABLE INTERLAMINAR SHEAR FAILURE

SHEAR AND TENSION SHEAR AND COMPRESSION

16B) NON - SHEAR MODES OF FAILURE - UNACCEPTABLE INTERLAMINAR SHEAR FAILURE

TENSION COMPRESSION

16C) NON - SHEAR MODES OF FAILURE - UNACCEPTABLE INTERLAMINAR SHEAR FAILURE



16D) PLASTIC SHEAR - UNACCEPTABLE INTERLAMINAR SHEAR FAILURE

FIG. 16 MODES OF FAILURE

ANNEX B

(*Clauses* 5.1, 6.7 *and* 7.7)

ULTRASONIC INSPECTION

B-1 GENERAL

This Annex is based on techniques used by other techniques of ultrasonic inspection, provided these have been demonstrated to be suitable for the manufacturing method.

B-2 GENERAL REQUIREMENTS

The outer and inner surfaces of any cylinder which is to be tested ultrasonically shall be in a condition suitable for an accurate and reproducible test. For flaw detection, the pulse echo system shall be used. For thickness measurement either the resonance method or the pulse echo system shall be used. Either contact or immersion techniques of testing shall be used. A coupling method which ensures adequate transmission of ultrasonic energy between the testing probe and the cylinder shall be used.

B-3 FLAW DETECTION OF THE CYLINDRICAL PARTS

B-3.1 Procedure

The cylinders to be inspected and the search unit shall have a rotating motion and translation relative to one another such that a helical scan of the cylinder is described. The velocity of rotation and translation shall be constant within ± 10 percent. The pitch of the helix shall be less than the width covered by the probe (at least a 10 percent overlap shall be guaranteed) and be related to the effective beam width, such as, to ensure 100 percent coverage at the velocity of rotation and translation used during the calibration procedure. An alternative scanning method may be used for transverse defect detection, in which the scanning or relative movement of the probes and the work piece is longitudinal, the sweeping motion being, such as, to ensure a 100 percent surface coverage with about 10 percent overlap of the sweeps. The cylinder wall shall be tested for longitudinal defects with the ultrasonic energy transmitted in both circumferential directions and for transverse defects in both longitudinal directions. In this case or when optional testing is carried out on the transition areas between the wall and neck and/or wall and base, this may be conducted manually if not carried out automatically. The effectiveness of the equipment shall be periodically checked by passing a reference standard through the test procedure. This check shall be carried out at least at the beginning and end of each shift. If during this check the presence of the appropriate reference notch not detected then all cylinders tested subsequent to the last acceptance check shall be retested after the equipment has been reset.

B-3.2 Reference Standard

A reference standard of convenient length shall be prepared from a cylinder of similar diameter and wall thickness range, and from material with the same acoustic characteristic and surface finish as the cylinder to be inspected. The reference standard shall be free from discontinuities which may interfere with the detection of the reference notches.

Reference notches, both longitudinal and transverse, shall be matched on the outer and inner surface of the standard. The notches shall be separated such that each notch can be clearly identified.

The following dimensions and shape of notches are of crucial importance for the adjustment of the equipment (*see* Fig. 17 and Fig. 18):

a) Length of the notches (E) shall be no greater than 50 mm;
b) Width (W) shall be no greater than twice the nominal depth (T). However, where this condition cannot be met a maximum of 1 mmis acceptable;
c) Depth of the notches (T) shall be 5 percent ± 0.75 percent of the nominal thickness (S) with a minimum of 0.2 mm and a maximum of 1 mm, over the full length of the notch. Run outs at each end are permissible;
d) Notch shall be sharp edged at it’s inter section with surface of the cylinder wall. The cross section of the notch shall be rectangular except where spark erosion machining methods are used; then it is acknowledged that the bottom of the notch will be rounded; and
e) Shape and dimensions of the notch shall be demonstrated by an appropriate method.

B-4 CALIBRATION OF EQUIPMENT

Using reference standard described in **B-3.2**, the equipment shall be adjusted to produce clearly identifiable indications from inner and outer reference notches. The amplitude of the indications shall be as near equal as possible. The indication of smallest amplitude shall be used as the rejection level and for setting visual, audible, recording or sorting devices. The equipment shall be calibrated with the reference standard or probe, or both, moving in the same manner, in the same direction and at the same speed as will be used during the inspection of the cylinder. All visual, audible, recording or sorting devices shall operate satisfactorily at the test speed.

B-5 WALL THICKNESS MEASUREMENT

If the measurement of the wall thickness is not carried out at another stage of production, the cylindrical part shall be 100 percent examined to ensure that the thickness is not less than the guaranteed minimum value.

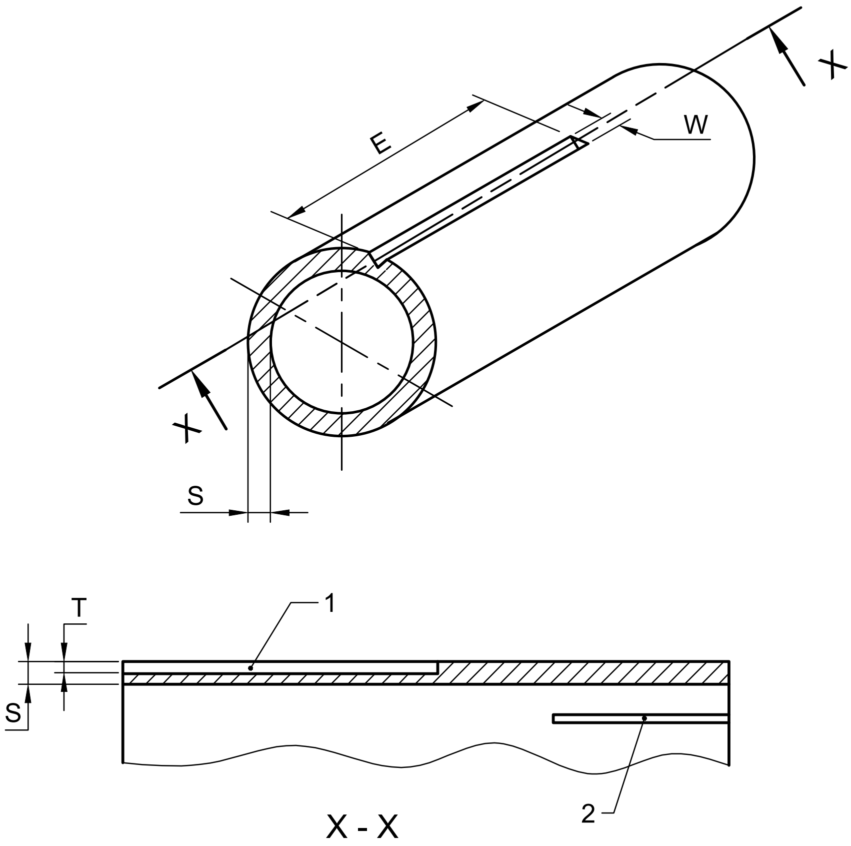
B-6 INTERPRETATION OF RESULT

Cylinders with indications which are equal to or greater than the lowest of the indications from the reference notches shall be withdrawn. Surface defects may be removed, after removal the cylinders shall be re-subjected to ultrasonic flaw detection and thickness measurement.

Any cylinder which is shown to be below the guaranteed minimum wall thickness shall be rejected.

B-7 CERTIFICATION

The ultrasonic testing shall be certified by the cylinder manufacturer. Every cylinder, which has passed the ultrasonic testing in accordance with this standard, shall be stamp-marked with the symbol '*UT*'.



Key

1) External reference notch 2) Internal reference notch

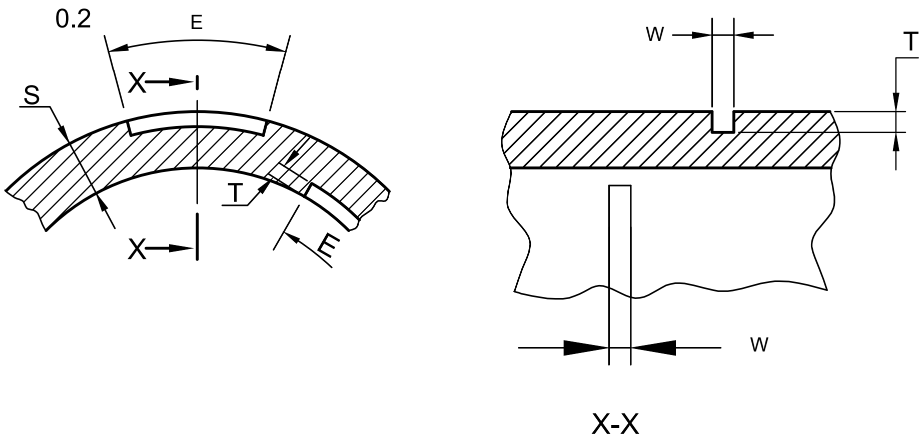
NOTE :-

$T \leqslant (5 \pm 0.75)\ \%\ S$ BUT $\leqslant 0.2$ mm $\leqslant T \leqslant 1$ mm

$W \leqslant 2T$ but if not possible then $W \leqslant$ mm

$E \leqslant 50$ mm

Fig. 17 Design Details and Dimensions of the Reference Notches for Longitudinal Defects



Note :-

T ⩽ (5 ± 0.75) % S BUT 0.2 mm ⩽ T ⩽ 1 mm

W ⩽ 2T, BUT IF NOT POSSIBLE THEN W ⩽ 1 mm

E ⩽ 50 mm

FIG. 18 SCHEMATIC REPRESENTATION OF THE REFERENCE NOTCHES FOR CIRCUMFERENTIAL DEFECTS

ANNEX C

(*Clauses* 5.2.6, 6.3.4 *and* 7.3.4)

NDE DEFECT SIZE BY FLAWED CYLINDER CYCLING

C-1 The following procedure can be used to determine the NDE defect size for metal lined hoop wrapped and metal lined full wrapped designs:

a) Introduce internal flaws in the metallic liner. 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 to failure three cylinders containing these artificial defects in accordance with the test method specified in **A-12**.

If the cylinders do not leak or rupture in less than 1 000 cycles multiplied by the specified service life in years, then the allowable defect size for NDE is equal to or less than the artificial flaw size at that location.

ANNEX D

(*Clauses* 6.3.2, 7.3.2 *and* 8.3.2)

D-1 VERIFICATION OF STRESS RATIOS USING STRAIN GAUGES

This Annex describes a procedure that may be used to verify stress ratios by use of strain gauges:

a) The stress-strain relationship for fibre is always elastic and therefore the stress ratios and the strain ratios are equal.
b) High elongation strain gauges are required.
c) Strain gauges should be orientated in the direction of the fibre on which they are mounted (that is, with hoop fibre on the outside of the cylinder, mount gauges in the hoop direction).

D-2 METHOD 1 (APPLIES TO CYLINDERSTHAT DO NOT USE HIGH TENSION WINDING)

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

D-3 METHOD 2 (APPLIES TO ALL CYLINDERS)

a) At zero pressure after winding and Autofrettage, apply strain gauges and calibrate.
b) Measure strains at zero, working and minimum burst pressures.
c) At zero pressure, after strain measurements have been taken at the working 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.
d) Adjust the strain reading at zero, operating, and minimum burst pressure by the amount of strain measured at zero pressure with and without the liner.
e) Confirm that the strain at burst pressure divided by strain at working pressure meets the stress ratio requirements. For hybrid construction, the strain at operating is compared with the rupture strain of cylinders reinforced with a single fibre type.

ANNEX E

(*Clauses* 6.4.5, 6.5.2.9, 7.4.4, 7.5.2.9 *and* 8.4.4)

ENVIRONMENTAL TEST

E-1 GENERAL

This optional test is applicable to all types of cylinders covered in this standard.

E-2 CYLINDER SET-UP AND PREPARATION

Two cylinders are tested in a condition representative of installed geometry including coating (if applicable), brackets and gaskets, and pressure fittings using the same sealing configuration (that is O-rings) as that used in service. Brackets may be painted or coated prior to installation in the immersion test if they are painted or coated prior to vehicle installation.

The cylinders are subjected to pre-conditioning in accordance with **E-3** and then exposed to a sequence of environments, pressures and temperatures in accordance with **E-5**.

Although pre-conditioning and fluid exposure is performed on the cylindrical section of the cylinder, all of the cylinder, including the domed sections, should be as resistant to the exposure environments as are the exposed areas.

As an alternative, a single cylinder approach may be used in which both the immersion environment and other fluids exposure tests are carried out on one cylinder. In this case, care should be taken to prevent cross contamination among the fluids.

E-3 PRE-CONDITIONING

E-3.1 Pre-conditioning Apparatus

The following types of apparatus are needed for preconditioning the test cylinder by pendulum and gravel impact.

a) Pendulum impact apparatus, comprising of:
   1) an impact body of steel having the shape of a pyramid with equilateral triangle faces and a square base, the submit and the edges being rounded to a radius of 3 mm;
   2) a pendulum, the centre of percussion of which coincides with the centre of gravity of the pyramid, its distance from the axis of rotation of the pendulum being 1m and the total mass of the pendulum referred to its centre of percussion being15 kg; and
   3) a means of determining that the energy of the pendulum at the moment of impact is not less than 30 N.m and is as close to that value as possible, and a means of holding the cylinder in position during impact by the end bosses or by the intended mounting bracket.
b) Gravel impact machine, comprising of:
   1) an impact machine, constructed according to the design specifications shown in Fig. 19 and capable of being operated in accordance with ASTM D3170 except that the cylinder may beat ambient temperature during gravel impact; and
   2) gravel, comprising alluvial road gravel passing through a 16 mm space screen but retained on a 9.5 mm space screen. Each application is to consist of 550 ml of graded gravel (approximately 250 to 300 stones).

E-3.2 Pre-conditioning Procedure

E-3.2.1 *Pre-conditioning for the Immersion*

E-3.2.1.1 *Environment test*

Pre-conditioning by both pendulum impact and gravel impact is required for the portion of the container to be used for the 'immersion environment' test (*see* **E-4.1**).

With the cylinder unpressurized, pre-condition the central section of the cylinder that will be submerged, by an impact of the pendulum body at three locations spaced approximately 150 mm apart. Following impact, pre-condition each of the three locations by gravel impact application.

Additionally, pre-condition a location within the submerged portion of each domed section and 50 mm (measured axially) from the tangent by a single impact of the pendulum body.

E-3.2.2 *Pre-conditioning for the Other Fluid Exposure Test*

Pre-conditioning by gravel impact only is required for the portion of the container to be used for the 'other fluid exposure' test (*see* **E-4.2**).

Divide the upper section of the cylinder used for the 'other fluids exposure' test into 5 distinct areas of nominal diameter 100 mm and mark these for pre-conditioning and fluid exposure (*see* Fig. 20). Ensure that the areas do not overlap on the cylinder surface and, for the single cylinder approach, do not overlap the immersed section of the cylinder. While convenient for testing, the areas need not be oriented along a single line.

With the cylinder unpressurized, pre-condition each of the 5 areas identified in Fig. 20 for other fluid exposure on the cylinder by gravel impact application.

E-4 ENVIRONMENTS

E-4.1 Immersion Environment

At the appropriate stages in the test sequence (*see* Table 10) orient the cylinder horizontally to immerse the lower third of the cylinder diameter in a simulated and rain/road salt water solution composed of the following compounds:

a) De-ionized water;
b) Sodium chloride: 2.5 percent (mass fraction): ± 0.1 percent;
c) Calcium chloride: 2.5 percent (mass fraction): ± 0.1 percent; and
d) Sulphuric acid: sufficient to achieve a solution *p*H of 4.0 ± 0.2.

Adjust the solution level and *p*H prior to each test step which uses this liquid. Maintain the temperature of the bath at 21 ± 5 °C. During immersion, hold the unsubmerged section of the cylinder in ambient air.

E-4.2 Other Fluid Exposures

At the appropriate stages in test sequence (*see* Table 10) expose each marked area to one of five solutions for 30 min. Use the same environment for each location throughout the test. The solutions are:

a) Sulphuric acid : 19 percent (volume fraction) aqueous solution;
b) Sodium hydroxide : 25 percent (mass fraction) aqueous solution;
c) Methanol/gasoline : 30/70 percent concentrations;
d) Ammonium nitrate : 29 percent (mass fraction) aqueous solution; and
e) Windscreen washer fluid.

During the exposure, orient the test cylinder with the exposure area uppermost. Place a pad of glass wool one layer thick approximately 0.5 mm and trimmed to the appropriate dimensions on the exposure area. Using a pipette, apply 5 ml of the test fluid to the glass wool. Ensure that the pad is wetted evenly across its surface and through its thickness. Pressurize the cylinder and remove the gauge pad after pressurization for 30 min.

E-5 TEST CONDITIONS

E-5.1 Pressure Cycle

At the appropriate stage in the test sequence (*see* Table 10), subject the cylinder to hydraulic pressure cycles of between 20 bar and 260 bar for the ambient and high temperature steps, and between 20 bar and 160 bar for the lower temperature steps. Hold the maximum pressure for a minimum of 60 s and ensure that each full cycle takes no less than 66 s.

E-5.2 High and Low Temperature Exposure

At the appropriate stages in the test sequence (*see* Table 10), bring the surface of the cylinder to a high or low temperature in air. The low temperature shall be no higher than –35 °C and the high temperature shall be 82 ± 5 °C as measured on the surface of the cylinder.

E-6 TEST PROCEDURE

The test procedure is as follows:

a) Pre-condition the cylinders (or cylinder in the single cylinder approach) in accordance with **E-3.2**;
b) Carry out the sequences of environmental exposure, pressure cycling and temperature exposure as defined in Table 10. Do not wash or wipe the cylinder surface between stages; and
c) Following completion of the sequences, subject the cylinders (or cylinder) to a hydrostatic pressure burst test to destruction in accordance with **A-11**.

E-7 ACCEPTABLE RESULTS

The test is considered to be satisfied if the burst pressure of the cylinders (or cylinder) is no less than 1.8 times the service pressure.

Table 10 Test Conditions and Sequence

(*Clauses* E-4.1, E-4.2, E-5.1, E-5.2 *and* E-6)

Test Steps			Environments	Number of Pressure Cycles	Temperature
Two Cylinder Approach		Single Cylinder Approach			
Immersion cylinder	Other fluids	Alternative single cylinder			
–	1	1	Other fluids (40 min)	–	Ambient
1	–	2	Immersion	500 X service life (years)	Ambient
–	2	–	Air	500 X service life (years)	Ambient
–	3	3	Other fluids (40 min)	–	Ambient
2	4	4	Air	250 X service life (years)	Low
–	5	5	Other fluids (40 min)	–	Ambient
3	6	6	Air	250 X service life (years)	High

ANNEX F

(*Clause* 10)

MANUFACTURER’S INSTRUCTIONS FOR HANDLING, USE AND INSPECTION OF CYLINDERS

F-1 GENERAL

The primary function of the manufacturer’s instructions is to provide guidance to the cylinder purchaser, distributor, installer and user for the safe use of the cylinder over its intended service life.

F-2 DISTRIBUTION

The manufacturer should advise the purchaser to supply these instructions to all parties involved in the distribution, handling, installation and use of the cylinders. The document may be reproduced to provide sufficient copies for this purpose; however, it should be marked to provide reference to the cylinders being delivered.

F-3 REFERENCE TO EXISTING CODES, STANDARDS AND REGULATIONS

Specific instructions may be stated by reference to national or recognized codes, standards and regulations.

F-4 CYLINDER HANDLING

Handling procedures should be described which would ensure that the cylinders will not suffer unacceptable damage or contamination during handling.

F-5 INSTALLATION

F-5.1 Installation instructions should be provided which would ensure that the cylinders do not suffer unacceptable damage during installation and during normal operation over the intended service life. Where the mounting is specified by the manufacturer, the instructions should, where relevant, contain details, such as, mounting design the use of the resilient gasket materials, the correct tightening torques and avoidance of direct exposure of the cylinder to the environment, chemicals and mechanical contacts. Cylinder locations and mountings should comply with recognized installation standards. Where the mounting is not specified by the manufacturer, the manufacturer should draw the purchaser’s attention to possible long term impacts of the vehicle mounting system, for example, vehicle body movements and cylinder expansion/contraction unless the pressure and temperature conditions of service. Where applicable the purchaser’s attention should be drawn to the need to provide installations such that liquids or solids cannot be collected to cause cylinder material damage. The correct pressure relieve device to be fitted should be specified. Cylinder valves, pressure relief of devices and connections should be protected against breakage in a collision. If this protection is the cylinder the decision and method of attachment should be approved by the cylinder.

F-5.2 Factors to be considered include the ability of the cylinder to support any transferred impact loads and the effect of localized strain on cylinder stresses and fatigue life.

F-6 IN-SERVICE INSPECTION

F-6.1 The manufacturer should clearly specify the user’s obligation to observe the required cylinder inspection requirements (for example, re-inspection interval, by authorized personnel). This information should be in agreement with the design approval requirements, and should cover.

F-6.1.1 *Periodic Re-qualification*

F-6.2 Inspection and/or testing are required to be performed in accordance with the statutory authority.

F-6.3 Recommendations for periodic re-qualification by visual inspection or testing during the service life should be provided by the cylinder manufacturer on the basis of use under service conditions specified herein. Each cylinder should be visually inspected at least every 48 months, and at the time of any re-installation, for external damage and deterioration, including under the support straps. The visual inspection should be performed by a competent agency approved or recognized by the regulatory authority, in accordance with the manufacturer's specifications.

F-6.4 Cylinders without labels or stamps containing mandatory information or with labels or stamps containing mandatory information that is illegible in any way should be removed from service. If the cylinder can be positively identified by manufacturer and serial number a replacement label or stamping may be applied, allowing the cylinder to remain in service.

F-6.4.1 *Cylinders Involved in Collisions*

Cylinders that have been involved in a vehicle collision should be re-inspected by an authorized inspection agency. Cylinders that 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.

F-6.4.2 *Cylinders Involved in Fires*

F-6.5 Cylinders that have been subjected to the action of fire should be re-inspected by an authorized inspection agency, or condemned and removed from service.

(*Continued from second cover*)

Owners and users of cylinders should note that cylinders designed according to this standard are to operate safely, if used in accordance with specified service conditions for a specified finite service life only. The expiry date is marked on each cylinder and, it is the responsibility of the owner and user to ensure that cylinders are periodically tested as per norms laid down by statutory authorities.

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 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Bureau of Indian Standards

BIS is a statutory institution established under the *Bureau of Indian Standards Act*, 2016 to promote harmonious development of the activities of standardization, marking and quality certification of goods and attending to connected matters in the country.

Copyright

Review of Indian Standards

Amendments are issued to standards as the need arises on the basis of comments. Standards are also reviewed periodically; a standard along with amendments is reaffirmed when such review indicates that no changes are needed; if the review indicates that changes are needed, it is taken up for revision. Users of Indian Standards should ascertain that they are in possession of the latest amendments or edition by referring to the latest issue of 'BIS Catalogue' and 'Standards: Monthly Additions'.

This Indian Standard has been developed from Doc No.: MED 16 (12095).

Amendments Issued Since Publication

Amend No.	Date of Issue	Text Affected

BUREAU OF INDIAN STANDARDS

Headquarters:

Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi 110002
Telephones: 2323 0131, 2323 3375, 2323 9402 *Website*: www.bis.gov.in

Regional Offices:		*Telephones*
Central	: Manak Bhavan, 9 Bahadur Shah Zafar Marg NEW DELHI 110002	2323 7617 2323 3841
Eastern	: 1/14 C.I.T. Scheme VII M, V.I.P. Road, Kankurgachi KOLKATA 700054	2337 8499, 2337 8561 2337 8626, 2337 9120
Northern	: Plot No. 4-A, Sector 27-B, Madhya Marg CHANDIGARH 160019	265 0206 265 0290
Southern	: C.I.T. Campus, IV Cross Road, CHENNAI 600113	2254 1216, 2254 1442 2254 2519, 2254 2315
Western	: Manakalaya, E9 MIDC, Marol, Andheri (East) MUMBAI 400093	2832 9295, 2832 7858 2832 7891, 2832 7892

Branches : AHMEDABAD. BENGALURU. BHOPAL. BHUBANESHWAR. COIMBATORE. DEHRADUN. DURGAPUR. FARIDABAD. GHAZIABAD. GUWAHATI. HYDERABAD. JAIPUR. JAMMU. JAMSHEDPUR. KOCHI. LUCKNOW. NAGPUR. PARWANOO. PATNA. PUNE. RAIPUR. RAJKOT. VISAKHAPATNAM.

Published by BIS, New Delhi