# Spoolable Reinforced Plastic Line Pipe

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# Spoolable Reinforced Plastic Line Pipe

## 1 Scope

This specification provides requirements for the manufacture and qualification of spoolable reinforced plastic line pipe in oilfield and energy applications including transport of multiphase fluids, hydrocarbon gases, hydrocarbon liquids, oilfield production chemicals, and nonpotable water. Also included are performance requirements for materials, pipe, and fittings.

These products consist of a liner, a reinforcement layer consisting of helically wrapped steel or nonmetallic reinforcing elements, and an outer cover. The helical reinforcing elements shall be a single material. Reinforcement tapes, with either metal wire or non-metallic reinforcement fibers, and a matrix material, are considered as single material. Additional nonhelical reinforcing elements are acceptable. The spoolable reinforced line pipe under this specification is capable of being spooled for storage, transport and installation. For offshore use, additional requirements may apply and are not within the scope of this document.

This specification is limited to pipe and end-fittings and couplings and does not relate to other system components and appurtenances. Where other system components (e.g. elbows, tees, valves) are of conventional construction they will be governed by other applicable codes and practices.

## 2 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document applies (including any addenda/errata).

API Specification Q1, *Specification for Quality Management System Requirements for Manufacturing Organizations for the Petroleum and Natural Gas Industry*

API Recommended Practice 17B, *Recommended Practice for Flexible Pipe*

API Specification 17J, *Specification for Unbonded Flexible Pipe, 4th Edition*

API 1104, *Standard for Welding Pipelines and Related Facilities*

ASME[1] B31.3, *Process Piping*

ASME BPVC. Section IX, *Welding and Brazing Qualifications*

ASTM[2] A370, *Standard Test Method and Definitions for Mechanical Testing of Steel Products*

ASTM A751, *Standard Test Methods, Practices, and Terminology for Chemical Analysis of Steel Products*

ASTM D256, *Standard Test Methods for Determining the Izod Pendulum Impact Resistance of Plastics*

ASTM D638, *Standard Test Method for Tensile Properties of Plastics*

ASTM D695, *Standard Test Method for Compressive Properties of Rigid Plastics*

ASTM D746, *Standard Test Method for Brittleness Temperature of Plastics and Elastomers by Impact*

ASTM D792, *Standard Test Method for Density and Specific Gravity (Relative Density) of Plastics by Displacement*

ASTM D885, *Standard Test Methods for Tire Cords, Tire Cord Fabrics, and Industrial Filament Yarns*

[1] American Society of Mechanical Engineers, Two Park Avenue, New York, NY 10016-5990, www.asme.org

[2] ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428

*Made from Manufactured Organic Base Fibers*

ASTM D1505, *Standard Test Method for Density of Plastics by the Density-Gradient Technique*

ASTM D1598, *Test Method for Time-To-Failure of Plastic Pipe under Constant Internal Pressure*

ASTM D1599, *Test Method for Resistance to Short-Time Hydraulic Pressure of Plastic Pipe, Tubing, and Fittings*

ASTM D2256, *Standard Test Method for Tensile Properties of Yarns by the Single Strand Method*

ASTM D2412, *Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading*

ASTM D2444, *Standard Test Method for Determination of the Impact Resistance of Thermoplastic Pipe and Fittings by Means of a Tup (Falling Weight)*

ASTM D2565, *Standard Practice for Xenon-Arc Exposure of Plastics Intended for Outdoor Applications*

ASTM D2990, *Standard Test Methods for Tensile, Compressive, and Flexural Creep and Creep-Rupture of Plastics*

ASTM D2992-18, *Practice for Obtaining Hydrostatic or Pressure Design Basis for "Fiberglass" (Glass-Fiber- Reinforced Thermosetting Resin) Pipe and Fittings*

ASTM D3222, *Standard Specification for Unmodified Poly (Vinylidene Fluoride) (PVDF) Molding Extrusion and Coating Materials*

ASTM D3350, *Standard Specification for Polyethylene Pipe and Fittings Materials*

ASTM D3418-12e1, *Standard Test Method for In-Plane Shear Response of Polymer Matrix Composite Materials by Tensile Test of a ±45° Laminate*

ASTM D4000, *Standard Classification System for Specifying Plastic Materials*

ASTM D4067, *Standard Classification System for and Basis for Specification for Reinforced and Filled Poly (Phenylene Sulfide) (PPS) Injection Molding and Extrusion Materials Using ASTM Methods*

ASTM D4101, *Standard Specification for Polypropylene Injection and Extrusion Materials*

ASTM D5575, *Standard Classification System for Copolymers of Vinylidene Fluoride (VDF) with Other Fluorinated Monomers*

ASTM D5857, *Standard Specification for Polypropylene Injection and Extrusion Materials Using ISO Protocol and Methodology*

ASTM D6358, *Standard Classification System and Basis for Specification for Poly (Phenylene Sulfide) (PPS) Injection Molding and Extrusion Materials Using ISO Methods*

ASTM D6779, *Standard Classification system for and Basis of Specification for Polyamide Molding and Extrusion Materials (PA)*

ASTM D7269, *Standard Test Methods for Tensile Testing of Aramid Yarns*

ASTM E328, *Standard Test Methods for Stress Relaxation Tests for Materials and Structures*

ASTM E739, *Standard Practice for Statistical Analysis of Linear or Linearized Stress-Life (S-N) and Strain-Life (ε-N) Fatigue Data*

ASTM E1356, *Standard Test Method for Assignment of the Glass Transition Temperatures by Differential Scanning Calorimetry*

ISO 1167-1, *Thermoplastics pipes, fittings and assemblies for the conveyance of fluids — Determination of the resistance to internal pressure — Part 1: General Method*

ISO[3] 4437-1:2014, *Plastics piping systems for the supply of gaseous fuels*

ISO 9001, *Quality Management Systems—Requirements*

ISO 11357, *Differential scanning calorimetry (DSC)*

ISO 15156, *Petroleum and natural gas industries-Materials for use in $H_2S$-containing environments in oil and gas production*

ISO 17025, *General requirements for the competence of testing and calibration laboratories*

ISO/IEC 17020, *Conformity assessment—Requirements for the operation of various types of bodies performing inspection*

ISO/IEC 17065, *Conformity assessment—Requirements for bodies certifying products, processes and services*

ISO 23936-1, Petroleum, petrochemical and natural gas industries -- Non-metallic materials in contact with media related to oil and gas production -- Part 1: Thermoplastics

ISO 23936-2, Petroleum, petrochemical and natural gas industries -- Non-metallic materials in contact with media related to oil and gas production -- Part 2: Elastomers

ISO/TS 29001, *Petroleum, Petrochemical, and Natural Gas Industries—Sector-Specific Quality Management Systems - Requirements for Product and Service Supply Organizations*

NACE[4] MR0175, *Petroleum and natural gas industries-Materials for use in H2S-containing environments in oil and gas production*

NACE TM0177, *Laboratory Testing of Metals for Resistance to Sulfide Stress Cracking and Stress Corrosion Cracking in $H_2S$ Environments*

*NORSOK M-710, Qualification of Non-metallic Sealing Materials and Manufacturers*

PPI[5] TR-3, *Policies and Procedures for Developing Hydrostatic Design Basis (HDB), Pressure Design Basis (PDB), Strength Design Basis (SDB), and Minimum Required Strength (MRS) Ratings for Thermoplastic Piping Materials or Pipe*

*PPI TR-19, Chemical Resistance of Thermoplastics Piping Materials*



[3] International Organization for Standardization, ISO publications are available from the American National Standards Institute (ANSI), 25 West 43rd Street, 4th Floor, New York, NY 10036, www.iso.org, www.ansi.org

[4] National Association of Corrosion Engineers International, 1440 South Creek Drive, P.O. Box 218340, Houston, TX 77218-8340, www.nace.org

[5] Plastics Pipe Institute, 105 Decker Court, Suite 825, Irving, TX 75062, www.plasticpipe.org

# 3 Terms, Definitions, and Abbreviations

For the purposes of this document, the following terms, definitions, and abbreviations apply.

## 3.1 Terms and Definitions

**3.1.1**
**batch**
Pipe produced sequentially with no interruptions or shutdowns that are not a part of the normal production process.

NOTE In this document, “batch” refers to manufactured product; “lot” refers to raw material components.

**3.1.2**
**blistering**
Damage in the form of gas-filled pockets caused by the release of absorbed gas on depressurization within a solid polymer layer (e.g. polymeric liner).

**3.1.3**
**brittle failure**
A failure mode which exhibits no visible (to the naked eye) permanent material deformation (stretching, elongation, or necking down) in the area of the break.

**3.1.4**
**connector**
Device used to provide a leak-tight (except to vent gas where applicable) structural connection between the end-fitting and adjacent piping (e.g. bolted flanges, clamped hubs, and proprietary connectors).

**3.1.5**
**coupling**
Specific type of fitting developed for joining one section of pipe to another. (e.g. in-line connector)

**3.1.6**
**coupon**
A test piece cut from a representative specimen.

**3.1.7**
**cover**
Protective outer sheath of the pipe.

**3.1.8**
**creep rupture**
Failure as a result of a period under steady stress or pressure (also known as static fatigue).

**3.1.9**
**cyclic loading**
More than 7000 cycles and $\Delta P/NPR > 6$ % where $\Delta P$ is maximum to minimum amplitude.

**3.1.10**
**deplasticization**
Extraction or loss of any of a group of additive substances in a polymer formulation that are used to impart flexibility or other properties to the finished product.

**3.1.11**
**design life**
A period of time used in design calculations, selected for the purpose of verifying that a replaceable or permanent component is suitable for the anticipated period of service.

NOTE A properly maintained and protected pipeline system may be able to provide longer service with proper justification.

**3.1.12**
**disbond**
Separation of the bonded layers.

**3.1.13**
**end-fitting**
A mechanical device that forms the transition from the pipe to the connector.

**3.1.14**
**factor, design**
**$F_d$**
A number less than or equal to one that takes into consideration the manufacturing and testing variables, including normal variations in the material, manufacture, dimensions, handling and installation techniques, and the precision and bias of the test methods.

**3.1.15**
**factors, service**
**$F_{Sn}$**
A group of operating factors each less than or equal to one that considers the application or use and may include environment (fluids), cycling loading, and temperature as described in this document.

**3.1.16**
**field-fitting**
End-fitting or coupling designed for permanent installation.

**3.1.17**
**function**
Action(s) that an item is designed to perform.

**3.1.18**
**laboratory test fitting**
Used for testing to determine the properties of the pipe body.

**3.1.19**
**liner**
Continuous polymeric layer that is in contact with the conveyed fluid.

**3.1.20**
**liner collapse**
Movement of the liner away from the structural layer on reduction of internal pressure.

**3.1.21**
**lower confidence limit**
**LCL**
Hydrostatic pressure calculated for a specific time-to-failure using Formula A1.25 in ASTM D2992-18, replacing $\sigma y$ by $\sigma n$ in accordance with A1.4.6.4 in ASTM D2992-18.

NOTE For 95 % confidence limits, there is a 2.5 % probability that the pipe's actual mean pressure versus time-to-failure regression line may fall below this calculated LCL.

**3.1.22**
**lower prediction limit**
**LPL**
Hydrostatic pressure calculated for a specific time-to-failure using Formula A1.25 in ASTM D2992-18.

NOTE For 95 % prediction limits, there is a 2.5 % probability that an individual data point may fall below this calculated LPL.

**3.1.23**
**lowest allowable installation temperature**
Lowest allowable pipe temperature for deployment, e.g. unspooling.

**3.1.24**
**manufacturer**
Entity that fabricates products according to this specification

**3.1.25**
**maximum pressure rating**
**MPR**
The estimated maximum internal hydrostatic pressure that can be applied continuously to a pipe with a high degree of certainty that failure of the component will not occur.

**3.1.26**
**maximum operating pressure**
**MOP**
Pressure obtained by multiplying the NPR by application related service factors.

**3.1.27**
**operating MBR**
Minimum allowable bend radius for the installed and pressurized pipe.

**3.1.28**
**respooling MBR**
Minimum allowable bend radius when respooling the pipe in the factory or the field.

**3.1.29**
**handling MBR**
Minimum allowable bend radius the unpressurized pipe is subjected to during any handling.

**3.1.30**
**nominal pressure rating**
**NPR**
Pressure rating of the pipe as defined by the manufacturer and does not exceed the MPR.

**3.1.31**
**preconditioning**
The process of subjecting the pipe to a prescribed bend radius prior to testing. Preconditioning may

include a certain minimum number of bending cycles to the prescribed bend radius.

**3.1.32**
**product family**
Group of pipe products being a range of sizes and pressure ratings manufactured with the same material types, production process and process controls, and pipe construction.

**3.1.33**
**product family representative**
**PFR**
Product variant chosen for full qualification.

**3.1.34**
**product variant**
**PV**
Member of a product family with a specific pressure rating and diameter.

**3.1.35**
**purchaser**
A person, organization, or other entity that is a recipient of a pipeline product provided by a seller under a purchase order or contract of sale.

**3.1.36**
**qualified operator**
An individual who has been evaluated and can perform assigned covered tasks and recognize and react to abnormal operating conditions.

**3.1.37**
**qualified procedure**
Procedure subjected to sufficient testing to show that the procedure produces consistently reliable results and has been demonstrated to meet the specified requirements for its intended purpose.

**3.1.38**
**qualification test temperature**
Temperature at which pressure tests are carried out to establish the MPR for non-metallic reinforced products.

NOTE The pipe's MAOT cannot exceed the maximum qualification test temperature.

**3.1.39**
**qualification testing**
Activities performed prior to production with the intention of establishing the suitability of a product, design, procedure, or material and may be repeated periodically as a quality control measure but are distinct from production testing or batch release testing.

**3.1.40**
**regression analysis**
Statistical procedure to establish a long-term strength from stress rupture testing results carried out over a long period of time, typically greater than 10,000 hours.

**3.1.41**
**regression curve reference time**
**RCRT**
Time of 175,000 hours that is used in this specification to define MPR.

NOTE Pipe's design life can be less than, equal to, or greater than the RCRT.

**3.1.42**
**reinforcing elements**
The primary contributor to the hydrostatic strength of the pipe.

**3.1.43**
**rupture**
A tear, break, or fracture.

**3.1.44**
**service life**
Period of time during which the pipe fulfills all performance requirements.

**3.1.45**
**short-term burst pressure**
Burst pressure measured in a short-term test, where pressure is increased at a prescribed rate within a prescribed temperature range.

**3.1.46**
**spoolable pipe**
Pipe that is flexible enough to be provided as a coil or on a structural reel for transportation.

NOTE For the purposes of this specification, the terms coils, reels, and spools are used interchangeably.

**3.1.47**
**spoolable composite pipe**
Family of composite reinforced pipes in which the structural layer is flexible enough to enable spooling and unspooling.

NOTE This includes, but not limited to, S-GRE and RTP pipe.

**3.1.48**
**spoolable glass reinforced epoxy pipe (S-GRE)**
Type of spoolable composite pipe in which the structural layer typically consists of an even number of balanced helical windings of continuous glass fibers in an epoxy thermoset resin matrix.

**3.1.49**
**spoolable reinforced thermoplastic pipe (RTP)**
Type of spoolable composite pipe that consists of a thermoplastic liner on which is wound the structural layer typically consisting of an even number of balanced helical windings of reinforcement elements.

NOTE This includes, but not limited to, S-GRE, RTP, and S-GRE and RTP structures lined with PEX.

**3.1.50**
**tape**
Reinforcement type in which the strength elements are typically encapsulated in a matrix material and provided as a flat ribbon.

**3.1.51**
**Traceability**
The ability to identify the origin of materials and parts used to manufacture a product and/or the product processing or manufacturing history.

## 3.2 Abbreviations

| | |
|---|---|
| CLR | Crack Length Ratio |
| CSR | Crack Sensitivity Ratio |
| CTR | Crack Thickness Ratio |
| DMA | Dynamic Mechanical Analysis |
| DSC | Differential Scanning Calorimetry |
| $F_d$ | Design Factor |
| $F_{Sn}$ | Service Factor |
| HIC | Hydrogen Induced Cracking |
| LAOT | Lowest Allowable Operating Temperature |
| LCL | Lower Confidence Limit |
| $LCL_{RCRT}$ | LCL at time RCRT |
| LPL | Lower Prediction Limit |
| MBR | Minimum Bend Radius |
| MAOT | Maximum Allowable Operating Temperature |
| MOP | Maximum Operating Pressure |
| MPR | Maximum Pressure Rating |
| NPR | Nominal Pressure Rating |
| NPR_PV | Nominal Pressure Rating of the Product Variant |
| NPR_PFR | Nominal Pressure Rating of the Product Family Representative |
| $P_{PV1000}$ | 1000-hour Test Pressure of the Product Variant |
| $P_{PFR1000}$ | 1000-hour LCL Intercept Pressure of the Product Family Representative |
| PA | Polyamide or Nylon |
| PE | Polyethylene |
| PEX | Cross-linked Polyethylene |
| PFR | Product Family Representative |
| PM | Principal Mode |
| PPS | Polyphenylene Sulfide |
| PV | Product Variant |
| PVDF | Polyvinylidene Fluoride |
| QA | Quality Assurance |
| QC | Quality Control |
| RCRT | Regression Curve Reference Time |

| | |
|---|---|
| RTP | Reinforced Thermoplastic Pipe |
| SCE | Saturated Calomel Electrode |
| SMUTS | Specified Minimum Ultimate Tensile Strength |
| SMYS | Specified Minimum Yield Strength |
| SSC | Sulfide Stress Cracking |
| UV | Ultraviolet |

# 4 Materials

## 4.1 Materials Selection

The manufacturer shall be responsible for the selection and supply of all materials so that the materials meet the specified service and installation requirements.

## 4.2 Material Requirements

### 4.2.1 Liner

Sections 4.2.1.1 through 4.2.1.3 are applicable to liner applications and requirements.

#### 4.2.1.1 General

Polymeric compounds shall be specified using the standard classification systems described in Table 1.

Fitness for purpose shall be established in Section 5 and as specified in Table 2.

Masterbatch addition to the base resin is acceptable. If a masterbatch is used, only resin manufacturer approved masterbatches shall be used. The compound consisting of the base resin and approved masterbatch shall be considered as one material for the purposes of the substitution requirements of Section 5.4. As an alternative, if the masterbatch is not a resin manufacturer approved masterbatch the pipe manufacturer shall demonstrate that the compound meets the same cell classification per Table 1 as the manufacturer's masterbatch/base resin compound.

Fusion joints in the liner are permitted provided that they are performed by a qualified operator using a procedure qualified according to a recognized standard.

The liner shall be confirmed through testing to retain its integrity for the specified fluids under the given service conditions based on the property requirements in Table 2.

The final material properties after processing shall be within the acceptable range of properties for the given service conditions, and verified based the material qualification program in this section, and the product qualification program in Section 5.

Reprocessed material shall not be used.

Special care may be required for liner materials that are strong crystallizers. Processing parameters as documented in 6.2 shall be specific and controlled to prevent unwanted changes in microstructure and the consequent unwanted changes in material properties.

Changes to the liner may require requalification—see 5.4 for additional information.

#### 4.2.1.2 Chemical Resistance and Aging

The manufacturer shall document the effects of the chemical components of the service environment at the design temperature on the liner materials. An engineering assessment shall be conducted to verify that the liner will retain integrity and fitness for purpose at the design conditions. The assessment shall be based on testing and experience and shall predict the aging or deterioration of the polymer under the influence of environment. As a minimum, polymer aging estimates shall consider temperature, water cut, and pH. Special attention should be given to deplasticization, loss and/or degradation of additive formulation

components, fluid absorption, and changes of dimensions.

Materials used by products covered by this standard shall be demonstrated to remain stable for the design life of the product, retaining the necessary performance characteristics required to meet the original design specification. An internationally accepted chemical resistance test method such as ISO 23936-1 or NORSOK M-710 should be used to establish compatibility with representative service fluids.

PPI TR-19 may be used as a screening tool for evaluating fluid compatibility.

#### 4.2.1.3 Blister Resistance

For single material liners it shall be shown that the material will not blister or sustain other damage visible with the unaided eye during rapid depressurization from the NPR and service conditions according to methods described by 6.2.3.3 of API 17J, Fourth Edition for material coupon testing. If the manufacturer applies an $F_{Sn}$ for gas service, the test shall be at NPR x $F_{Sn}$.

For multilayer coextruded liners it shall be shown that the liner structure will not blister or sustain other damage visible with the unaided eye and the adhesion between layers shall not be compromised during the Pipe Blowdown Test of Annex B. The use of a shorter test specimen than specified in Annex B is acceptable. Use the expected number of decompressions in service, or 20 cycles as a minimum. A single-sided exposure coupon test is also acceptable. If the manufacturer applies an $F_{Sn}$ for gas service, the test shall be at NPR x $F_{Sn}$.

**Table 1. Polymer Material Cell Classification Standards**

| Polymer | Standard | Title |
|---|---|---|
| Polyethylene (PE) | ASTM D3350 | *Standard Specification for Polyethylene Plastics Pipe and Fittings Materials* |
| All Polyamides (Nylons) | ASTM D6779 | *Standard Classification System for and Basis of Specification for Polyamide Molding and Extrusion Materials (PA)* |
| PPS | ASTM D6358 | *Standard Classification System and Basis for Specification for Poly (Phenylene Sulfide) (PPS) Injection Molding and Extrusion Materials Using ISO Methods* |
| | ASTM D4067 | *Standard Classification System for and Basis for Specification for Reinforced and Filled Poly (Phenylene Sulfide) (PPS) Injection Molding and Extrusion Materials Using ASTM Methods* |
| Polypropylene | ASTM D4101 | *Standard Specification for Polypropylene Injection and Extrusion Materials* |
| | ASTM D5857 | *Standard Specification for Polypropylene Injection and Extrusion Materials Using ISO Protocol and Methodology* |
| PVDF | ASTM D3222 | *Standard Specification for Unmodified Poly(Vinylidene Fluoride) (PVDF) Molding Extrusion and Coating Materials* |
| | ASTM D5575 | *Standard Classification System for Copolymers of Vinylidene Fluoride (VDF) with Other Fluorinated Monomers* |
| PEX | ASTM F876 | *Standard Specification for Crosslinked Polyethylene (PEX) Tubing*<br>NOTE Dimensional requirements do not apply to API 15S applications. |
| Other Polymers | ASTM D4000 | *Standard Classification System for Specifying Plastic Materials* |

**Table 2—Property Requirements for Materials of Construction**

| Characteristic | Tests | Standard | Liner | Reinforcement Layer | Cover |
|---|---|---|---|---|---|
| Permeation Characteristics | Fluid Permeability | API 17J, 4th Edition Paragraph 6.2.3.2 | X | | X |
| | Blistering Resistance | See 4.2.1.3 | X | | |
| Compatibility and Aging | Fluid Compatibility | See 4.2.1.2 and 4.2.2.1 | X | X | X |
| | Aging Tests | See 4.2.1.2 and 4.2.2.1 | X | X | X |
| | Weathering Resistance | ASTM D2565 | | | X |

### 4.2.2 Reinforcement Layer

#### 4.2.2.1 General

The reinforcement layer, including any bonding agents, shall sustain its integrity under the given service conditions. The manufacturer shall document the test data that demonstrates the short-term and long-term load bearing capabilities of the layer, temperature capabilities, required fluid compatibility, and aging characteristics of all materials employed (see Table 2). Joints or welds in the reinforcement shall be made according to a qualified procedure by a qualified operator.

Changes to the structural layer may require requalification—see 5.4 for additional information.

#### 4.2.2.2 Steel Reinforcement

##### 4.2.2.2.1 General

Steel materials used in spoolable pipe shall be purchased in accordance with either a written material specification or an industry standard. Heat treatments on reinforcement materials shall be performed in accordance with documented procedures.

The manufacturer shall prepare a material qualification report that documents the reinforcement conforms to the specified requirements.

Only materials with the same materials specification (including chemistry and processing history, i.e. heat treatment and cold deformation) as used in the qualification testing shall be regarded as qualified.

##### 4.2.2.2.2 Corrosion Resistance

Steel material selection shall consider corrosive attack appropriate to the environment to which the layer is exposed.

##### 4.2.2.2.3 Cathodic Charging

Steel reinforcement that is designed for or can be exposed to cathodic protection shall be subject to

qualification testing to confirm that the potential hydrogen evolution resulting from cathodic charging does not result in hydrogen embrittlement.

The testing shall be conducted on degreased coupons loaded to 75 % actual yield stress and immersed in de-aerated seawater (minimum 3 wt. % NaCl) with an applied potential of 1.05 V versus SCE. The cathodic charging shall be applied for a minimum duration of 150 hours. Post-test examination shall be conducted to confirm that no hydrogen blistering or cracking of the coupon has occurred.

#### 4.2.2.2.4 Sour Service

For products to be qualified for sour service applications, the threshold limits of the steel reinforcement to HIC and SSC shall be tested in accordance with NACE TM0177 or the manufacturer's specified criteria, with the following exceptions:

a) the test fluid shall be an aqueous solution saturated with a mixed gas comprising the equivalent partial pressure of $H_2S$, $CO_2$, and $CH_4$ in the annulus;

1) if the manufacturer does not have a verified model for calculating annulus conditions, the pipe bore equivalent partial pressures shall be used;

2) the $CH_4$ may be replaced with another inert gas;

b) testing shall be performed at ambient temperature;

c) test duration shall be 720 hours minimum;

d) in case of testing polymer-metal composite reinforcements, the test duration of 720 hours shall be extended by the time it takes the corrosives to permeate through the matrix material;

e) coupons shall be loaded to at least 90 % of SMYS;

f) tensile load tests or four-point bend tests shall be used; and

g) coupon dimensions may deviate from TM0177 requirements according to the shape of reinforcement used.

If applicable, production welds shall be included in steel reinforcements to be qualified for sour service applications.

The test coupons shall survive the 720-hour test without failure. Following a SSC test, the steel reinforcement susceptibility to HIC should be checked in accordance with Section 7 of NACE TM0284-2011. Unless otherwise agreed by the manufacturer and the purchaser, the acceptance criteria shall be as follows:

a) CLR < 15 %

b) CTR < 3 %

c) CSR < 1.5 %

In cases where wire or filament dimensions are less than 1 $mm^2$ and do not allow for HIC examination, an axial load failure test in accordance with ASTM A370 shall be conducted following SSC testing. The axial load at failure following SSC exposure shall meet the minimum specified axial load at failure value based upon minimum cross-sectional area and minimum mechanical properties of the reinforcement. The purchaser shall be aware that changes to operating conditions may affect pipe performance.

#### 4.2.2.3 Nonmetallic Fiber Reinforcement

##### 4.2.2.3.1 General

Fiber shall be roving or yarn or tapes and shall be purchased in accordance with a written material specification or industry standard. The specification shall, as a minimum, include required values and tolerances for physical and mechanical characteristics. The fiber shall meet all the general reinforcement layer requirements of 4.2.2.1 and with regard to the fluid compatibility requirements, particular attention shall be paid to hydrolysis and the effects of pH.

Fibers may be embedded in a matrix.

The manufacturer shall prepare a material qualification report that documents the reinforcement conforms to the specified requirements in this section.

Only materials with the same materials specification as used in the qualification testing shall be regarded as qualified.

##### 4.2.2.3.2 Glass Fiber

For glass fibers intended for use in a thermosetting or thermoplastic matrix, the glass fibers shall have a sizing that is compatible with the intended matrix material.

The glass fiber specification shall include filament diameter, strand tex, sizing, and material composition or material family classification.

##### 4.2.2.3.3 Aramid Fiber Reinforcement

Aramid fibers shall be filament yarns or polymer-coated tapes. The specification shall include short-term breaking load for the filament or yarn being specified in accordance with test method ASTM D7269 and shall also include the linear density of the fiber. For yarns, the twist in turns per unit length shall be reported.

##### 4.2.2.3.4 Polyester Fiber Reinforcement

Polyester fibers shall be filament yarns or polymer-coated tapes. The specification shall include short-term breaking load for the filament or yarn being specified in accordance with test method ASTM D885 or D2256, and shall also include the linear density of the fiber. For yarns, the twist in turns per unit length shall be reported.

##### 4.2.2.3.5 Matrix Material

The matrix material shall be purchased in accordance with a written material specification or industry standard and shall be a material suited for the intended purpose. Changes to the matrix material may require requalification—see 5.4 for additional information.

###### 4.2.2.3.5.1 Thermosetting Resin

The manufacturer shall define the degree of cure based on the technique (DSC or DMA), procedure and value obtained after measuring the $T_g$ on each of the pipe specimens (minimum 18) used to qualify the product in 5.3.2. The $T_g$ value of the thermosetting resin for QA/QC purpose shall be established as follows:

Where a manufacturer uses a thermosetting resin in the reinforcing structure the manufacturer shall use

qualification $T_g$ data to determine the ongoing manufacturing minimum $T_g$. The $T_g$ shall be measured and recorded from qualification testing (Section 5) prior to long term regression testing, the average $T_g$ and standard deviation of the qualified $T_g$s shall be recorded and maintained by the manufacturer. The manufacturer's ongoing QA factory minimum $T_g$ shall be defined as the highest value of the Average Qualified $T_g$s - three (3) standard deviations of the qualified $T_g$ and the minimum qualified $T_g$.

The manufacturer shall verify that the specimens used in the tests described in 5.3.2, 5.3.3, and 5.3.4 meet the specified value as determined in the paragraph above.

#### 4.2.2.3.5.2 Thermoplastic Resin

Thermoplastic resins shall be shown to retain integrity and fitness for purpose at the design conditions based upon tests as specified in Table 2.

#### 4.2.2.3.6 Composite Reinforcement

Composite tapes shall consist of reinforcing fibers that are encapsulated inside a thermoplastic polymer matrix. The tape specification shall include type of reinforcement fiber and matrix, dimensions, short term tensile strength of the tape using an appropriate industry accepted test method, density, and fiber weight content.

### 4.2.3 Cover Materials

Polymer materials used for cover layers manufactured by melt extrusion onto the pipe shall be specified using the standard classification systems described in Table 1. Fitness for purpose shall be established in accordance with Section 5 and as specified in Table 2. The cover material shall sustain its function for the service conditions.

Cover materials that are applied as self-adhesive tapes shall conform to an international product standard from ASTM, AWWA, ISO, or AAMP for protective tape coating systems intended for application to the exterior of steel pipes for corrosion control and protection from mechanical damage. Fitness for purpose shall be established in accordance with this section. The cover material shall sustain its function for the service conditions.

Reprocessed material shall not be used.

The cover shall have sufficient low temperature ductility for the intended installation conditions and operating temperature ranges. The resistance to installation loads and environmental conditions shall be documented if required by the application or by the purchaser. Brittleness temperature shall be at or below the minimum design temperature when tested in accordance with ASTM D746.

If PE is used for the cover, the UV resistance for transportation and short-term storage shall be Code C or Code E as defined in ASTM D3350 or ISO 4437.

The UV resistance of other cover materials for transportation and short-term storage should be documented and agreed upon between the manufacturer and the purchaser.

For pipe used in surface applications, the UV resistance should be documented and agreed upon between the manufacturer and the purchaser.

The cover shall meet the test requirements of 5.3.12.

Changes to the cover may require requalification—see 5.4 for additional information.

#### 4.2.4 End-fittings and Pipe-to-pipe Couplings (Field-fittings)

The field-fitting shall sustain its integrity under the given service conditions. The manufacturer shall document the test data that demonstrates the long-term integrity of the fitting.

##### 4.2.4.1 General

Fittings shall be fabricated from materials in accordance with either a written specification or an applicable industry standard. The fitting material shall sustain its function for the manufacturer specified service conditions. Only field-fittings qualified by the pipe manufacturer shall be used. Heat treatments on field-fitting materials shall be performed in accordance with documented procedures or specification.

##### 4.2.4.2 Welding of Fittings

Fittings fabricated with pressure containing welds shall require qualification to a suitable weld procedure specification in accordance with local pipeline regulatory requirements or at a minimum in accordance with ASME BPVC, Section IX. Weld inspection shall be performed in accordance with the local pipeline regulatory requirements or in accordance with ASME B31.3 or API 1104 requirements as applicable.

##### 4.2.4.3 Corrosion Resistance

Steel selection shall consider corrosive attack appropriate to the environment to which the fitting is exposed.

###### 4.2.4.3.1 Cathodic Charging

All metallic fitting components designed for, or that can be exposed to, cathodic protection shall be made of materials that are resistant to hydrogen embrittlement in the applicable environment.

The steel fittings shall be subject to qualification testing to confirm that the potential hydrogen evolution resulting from cathodic charging does not result in hydrogen embrittlement. The testing shall be conducted on degreased coupons loaded to 75 % actual yield stress and immersed in de-aerated seawater (minimum 3 % NaCl) with an applied potential of 1.05 V versus SCE. The cathodic charging shall be applied for a minimum duration of 150 hours. Post-test examination shall be conducted to confirm that no hydrogen blistering or cracking of the coupon has occurred.

###### 4.2.4.3.2 Sour Service

Materials for fitting components for sour service applications in contact with conveyed fluids shall be selected in accordance with NACE MR0175/ISO 15156. Where qualification testing of materials or weldments is required, it shall be conducted according to the test procedure NACE TM0177.

##### 4.2.4.4 End Fitting Connectors

All end-fitting connectors and connector components shall be in accordance with a recognized industry standard, or as specified by the purchaser.

## 5 Pipe Qualification Program

### 5.1 General

For an introduction to terminology used in this section, see Annex F.

Qualification requirements for the pipe bodies, end-fittings, couplings, and general characteristics are specified in this section. The manufacturer is responsible for demonstrating compliance with the provisions

of this specification. A qualification test report shall be kept on file by the manufacturer and a copy shall be available on request to the purchaser. Any purchaser may make any additional investigation deemed necessary to prove compliance by the manufacturer.

Where it is necessary to introduce joints of any type into the manufactured pipe, specimens containing joints shall either be employed in the full qualification procedure or be treated as a PV.

Thermoplastic liner butt welds are exempt from this provided the appropriate procedures are followed to ensure consistent high weld quality as described in 4.2.1.1.

The manufacturer shall state and be able to justify the minimum and maximum temperature at which an end-fitting or coupling may be installed on a pipe.

Changes that affect fit or function shall require requalification in accordance with 5.4.

#### 5.1.1 Product Family Description

A product family size range may extend in nominal diameter −2 in. (51 mm) / +4 in. (102 mm) from the PFR and between $^{1}/_{2}\times$ and $2\times$ the nominal pressure rating of the PFR. Size and/or pressure rating changes outside these ranges require full qualification as a new PFR. Changes within these ranges require qualification as Product Variants.

A PFR shall have a nominal diameter of at least 2 in. (51 mm) in accordance with 7.1 and shall be tested in accordance with 5.2 to determine properties for the product family.

### 5.2 Qualification Requirements for Pipe and Field-Fittings

Table 3 specifies the qualification requirements for steel reinforced pipe.

Table 4 specifies the qualification requirements for non-metallic reinforced pipe.

To qualify a PFR, all tests with an X in the PFR Column of Table 3 or 4 shall be conducted to the stated requirements in the Clause No./Reference column.

To qualify PVs, all tests marked in the Product Range Test Requirements columns of Tables 3 or 4 shall be conducted to the stated requirements in the Clause No./Reference column as follows:

- An X in the ALL PVs column indicates that each PV shall be tested
- An S in the PV Diameter column indicates that the Smallest Diameter in a PV family shall be tested.
- An L in the PV Diameter column indicates that the Largest Diameter in a PV family shall be tested.
- An L in the PV Pressure Rating column indicates that the lowest pressure rating in a PV family shall be tested.
- An H in the PV Pressure Rating column indicates that the highest pressure rating in a PV family shall be tested.
- All combinations of S and L, and L and H, per the aforementioned columns shall be tested to qualify the full range of PVs associated with the PFR. For example, S and L in the PV diameter and L and H in the PV Pressure Rating column indicates that the combinations SL, SH, LL and LH shall be tested.

All qualification tests specified in Tables 3 and 4 shall be carried out on spool pieces comprising the basic pipe body, together with one or more types of end-fitting, unless otherwise specified in the test protocols in Section 5.3.

End-fittings and couplings used in qualification shall be assembled in accordance with the manufacturer's written instructions. Where specified, only field-fittings qualified by the pipe manufacturer shall be used.

If field-fittings are used for the tests to determine the MPR, then the field fittings are considered to be qualified. The only permissible mode of failure when qualifying the field-fittings shall be tensile rupture of the reinforcement.

Where laboratory test fittings are used for the tests to determine the MPR, testing shall be performed in accordance with 5.3.1 for steel reinforced pipe or 5.3.4 for nonmetallic reinforced pipe using field-fittings to confirm that the field-fittings do not adversely affect the MPR. The only permissible mode of failure when testing is performed using laboratory fittings shall be tensile rupture of the reinforcement.

**Table 3 — Qualification Testing Requirements Pipe Using Steel Reinforcement**

| Qualification Requirement | Test | Minimum Number of Specimens per Size/ Pressure Rating/Test | Clause No./ Reference | Product Range Test Requirements | | | |
|---|---|---|---|---|---|---|---|
| | | | | PFR | ALL PVs | PV Diameter | PV Pressure Rating |
| Determination of MPR of Steel Reinforced Pipe | Minimum Burst Pressure | 5 | 5.3.1 | X | X | | |
| Elevated Temperature Test | End Fitting Seal Long Term Performance (each polymer material) | 1 | 5.3.5 | X | | S and L<br>**OR**<br>All | All<br>**OR**<br>L and H |
| Thermal Cycling | Temperature Cycling Test (each polymer material) | 2 | 5.3.6 | X | | S and L | H |
| Rapid Decompression Testing of Pipe Structure for Gas or Multiphase Service | Rapid Decompression Test at Max Design Temp | 1 | 5.3.7 & Annex B | X | | | H |
| Confirm Operating MBR | MBR/Respooling Test | 2 | 5.3.8.1 | X | | S and L | H |
| Confirmation of Handling MBR < Operating MBR | Precondition prior to MBR/Respooling Test | 2 | 5.3.8.2 | X | | S and L | H |
| Effects of Handling and Spooling | Preconditioning at Operating MBR | 2 | 5.3.8.3 | X | | S and L | H |
| Respooling Preconditioning | Respooling<br>$\geq$ 10 cycles at<br>$\leq$ Operating MBR | 2 | 5.3.8.4 | X | | | |
| Axial Load Capability | Max Allowable Axial Load Followed by Test | 2 | 5.3.9 | X | X | | |
| External Load Performance | 2 Point Radial Crush Test | 3 | 5.3.10 | | | L | L |
| Lowest Allowable Operating Temperature Test | Min Operating Temperature (each polymer material) | 2 | 5.3.11 | | | S and L | H |
| Impact Resistance | Impact Load Followed by Pressure Testing | 2 | 5.3.12 | X | | S and L | H |
| Thermal Expansion Coefficient | Axial Thermal Expansion Coefficient (TEC) Measurement<br>&<br>Hoop TEC where OD clearance critical | 2 | 5.3.13 | X | | S and L | H |
| Growth and Shrinkage on Application of Pressure | Pressure Elongation | 2 | 5.3.14 | X | | S and L | H |
| Cyclic Loading (only if product is intended for cyclic service) | Cyclic Regression Testing/Analysis | Per Annex E | Annex E | X | | | |

**Table 4 — Qualification Testing Requirements for Pipe Using Non-Metallic Reinforcement**

| Qualification Requirement | Test Description | Minimum Number of Specimens per Size/ Pressure Rating/Test | Clause No./ Reference | Product Range Test Requirements | | | |
|---|---|---|---|---|---|---|---|
| | | | | PFR | ALL PVs | PV Diameter | PV Pressure Rating |
| Determination of MPR of Nonmetallic Reinforced Pipe PFR | Long Term Hydrostatic Pressure Testing | 18 | 5.3.2 | X | | | |
| Determination of MPR of Non-metallic Reinforced Pipe PV | 1000-hour constant pressure test | 2 | 5.3.4 | | X | | |
| Elevated Temperature Test | End Fitting Seal Long Term Performance (each polymer material) | 1 | 5.3.5 | X | | S and L **OR** All | All **OR** L and H |
| Temperature Cycling Test | Thermal Cycling (each polymer material) | 2 | 5.3.6 | X | | S and L | H |
| Rapid Decompression Testing of Pipe Structure for Gas or Multiphase Service | Rapid Decompression Test at Max Design Temp | 1 | 5.3.7 Annex B | X | | | H |
| Confirmation of Operating MBR | MBR/Respooling Test | 2 | 5.3.8.1 | X | | S and L | H |
| Confirmation of Handling MBR < Operating MBR | Precondition prior to MBR/Respooling Test | 2 | 5.3.8.2 | X | | S and L | H |
| Effects of Handling and Spooling | Preconditioning at Operating MBR | 2 | 5.3.8.3 | X | | | |
| Respooling Preconditioning | Respooling ≥ 10 cycles at ≤ Operating MBR | 2 | 5.3.8.4 | X | | | |
| Axial Load Capability | Max Allowable Axial Load Followed by Test | 2 | 5.3.9 | X | X | | |
| External Load Performance | 2 Point Radial Crush Test | 3 | 5.3.10 | | | L | L |
| Lowest Allowable Operating Temperature Test | Min Operating Temperature (each polymer material) | 2 | 5.3.11 | | | S and L | H |
| Impact Resistance | Impact Load Followed by Pressure Testing | 2 | 5.3.12 | X | | S and L | H |
| Thermal Expansion Coefficient | Axial Thermal Expansion Coefficient (TEC) Measurement & Hoop TEC where OD clearance critical | 2 | 5.3.13 | X | | S and L | H |
| Growth and Shrinkage on Application of Pressure | Pressure Elongation | 2 | 5.3.14 | X | | S and L | H |
| Cyclic Loading (only if product is intended for cyclic service) | Cyclic Regression Testing/Analysis | Per Annex F | Annex F | X | | | |

## 5.3 Pipe Qualification Test Procedures

### 5.3.1 Determination of MPR of Steel Reinforced Pipe

The MPR shall be based on the calculated minimum burst pressure ($P_{burst,\ min}$) of the pipe.

The MPR of the PFR and all product variants shall be confirmed by burst pressure testing which shall be verified and certified by an independent third-party agency that conforms to ISO/IEC 17020 and/or ISO/IEC 17065 or shall be conducted at an ISO 17025 accredited laboratory. All failed specimens, including any that fail by modes other than the PM, shall be reported in the qualification report.

#### 5.3.1.1 Test Requirements

Unless otherwise specified, the test specimen length shall be in accordance with ASTM D1599. All tests shall be conducted with unrestrained ends. Laboratory test fittings are allowed. For nominal diameters eight inches and larger, shorter test specimens than those prescribed in ASTM D1599 may be used if the manufacturer can show by technical means that the reduced length is justified.

Because qualification testing is typically conducted at ambient temperature the manufacturer shall select a MAOT and validate by testing in accordance with 5.3.5.

#### 5.3.1.2 Preconditioning of Specimens by Bending

Preconditioning is the process of subjecting the pipe to a prescribed bend radius prior to testing. Preconditioning may include a certain minimum number of bending cycles to the prescribed bend radius.

The PFR test specimens shall either be preconditioned or identical specimens shall pass the tests described in 5.3.8. If preconditioning is deemed necessary as in accordance with 5.3.8, the test specimens shall be preconditioned to the stated allowable handling MBR or the stated allowable number of respooling cycles (or both if both tests are unsuccessful in 5.3.8) prior to performing PFR qualification testing.

#### 5.3.1.3 Confirmation of MPR

The MPR shall be confirmed by burst pressure testing on at least five specimens. The 97.5 % lower prediction bound of the set of burst specimens shall be calculated using the Student's t-distribution. For the MPR to be confirmed, the calculated 97.5 % lower prediction bound shall be greater than or equal to $MPR/F_d$. No single test specimen shall be below $MPR/F_d$. Refer to Annex I for the 97.5 % lower prediction bound calculation methodology.

#### 5.3.1.4 Permissible Failure Modes

The permissible mode of failure shall be tensile rupture of the reinforcement.

If there is a failure mode other than the permissible mode during qualification testing, then that test result shall be discarded in computing averages or plotting the data.

NOTE An example of a non-permissible failure mode is ejection of the pipe from the fitting or coupling.

#### 5.3.1.5 Short-term Burst Pressure

Short-term burst pressure testing shall be performed in accordance with API 17B or ASTM D1599, Method A. For the purposes of this standard, these test methods achieve the same objective and may be considered equivalent.

The duration of the test may be extended to accommodate larger diameter and higher pressure products and commonly available pressurization equipment. The test duration range used shall be a multiple of the range prescribed in ASTM D1599. The test duration range used shall be included in the qualification report and the same duration range shall be used for QA testing.

Preconditioning of specimens for short-term burst characteristics is not required. If preconditioning is used for establishing short-term burst characteristics the same preconditioning shall be used for QA testing.

#### 5.3.1.6 Maximum Pressure Rating

The MPR shall be calculated as follows:

$$MPR = P_{burst,\ min} \times F_d \quad (1)$$

where:

$P_{burst,\ min}$ is the calculated minimum burst pressure.

The manufacturer shall ensure the $P_{burst,\ min}$ is calculated based upon minimum cross-sectional area and minimum mechanical properties of the reinforcement.

A maximum design factor, $F_d = 0.5$ shall be employed and is based upon the following:

a) the fluid service is water (refer to Section 4 and Annex D for guidance on other fluids);

b) the loading is static (for cyclic loading, refer to Annex E); and

c) installed in full compliance with manufacturer's recommendations and requirements (refer to API 15S-IH for guidance on handling, installation and operation practices).

If operating conditions are outside these baseline conditions, an engineering assessment shall be conducted.

Fluid Service Factors may be applied to the product based upon local regulations and user requirements and are beyond the scope of this document. Guidelines for $F_{Sn}$s are presented in Annex D.

### 5.3.2 Determination of MPR of Nonmetallic Reinforced Pipe PFRs

The MPR shall be based on a design factor applied to the long-term hydrostatic pressure of the pipe.

The MPR of the PFR shall be confirmed by long-term hydrostatic pressure testing, which shall be verified and certified by an independent third-party agency that conforms to ISO/ IEC 17020 and/or ISO/IEC 17065 or shall be conducted at an ISO 17025 accredited laboratory.

#### 5.3.2.1 Test Requirements

All tests shall be conducted with unrestrained ends. Laboratory test fittings are allowed. For nominal diameters eight inches and larger, shorter test specimens than what is prescribed in ASTM D1598 or ISO 1167-1 may be used if the manufacturer can show by technical means that the reduced length is justified.

The qualification test temperature shall be selected by the manufacturer and shall be greater than or equal to the design temperature in any application for which the product is employed.

Water is typically used as the pressurizing fluid. If an alternate fluid is used it shall be specified in the qualification report.

#### 5.3.2.2 Preconditioning of Specimens

Preconditioning is the process of subjecting the pipe to a prescribed bend radius prior to testing. Preconditioning may include a certain minimum number of bending cycles to the prescribed bend radius.

The test specimens shall either be preconditioned to the handling MBR or operating MBR whichever is smaller as required in the applicable paragraph of 5.3.8, or shall pass the tests described in 5.3.8. If

preconditioning is deemed necessary in accordance with 5.3.8, the test specimens shall be preconditioned to the stated allowable handling MBR or the stated allowable number of respooling cycles (or both if both tests are unsuccessful in 5.3.8) prior to performing PFR qualification testing.

#### 5.3.2.3 Determination of MPR

Long-term hydrostatic pressure shall be developed and reported adhering to the methodology of ASTM D2992-18, Procedure B. ISO 1167-1 may be substituted for ASTM D1598 to determine long term hydrostatic strength for use in ASTM D2992-18 regression analysis provided that the manufacturer does not mix data acquired using the two methods when performing the D2992-18 regression analysis. No data points below 10 hours shall be included in regression calculations. All failed specimens, including any that fail by modes other than the PM, shall be reported in the qualification report.

The MPR shall be calculated as follows:

$$MPR = LCL_{RCRT} \times F_d \quad (3)$$

A maximum design factor, $F_d = 0.67$ shall be employed and is based upon the following:

a) maximum design temperature is equal to or less than the qualification temperature;

b) fluid service is water (you may refer to Annex D for guidance on other fluids);

c) loading is static (for cyclic loading, refer to Annex E); and

d) installed in full compliance with manufacturer's recommendations and requirements (refer to API 15S-IH for guidance on handling, installation and operation practices).

The manufacturer shall provide data that support the assumed design factor for their pipe pressure class/diameter with a target annual failure probabilities value of $10^{-5}$.

If operating conditions are outside these baseline conditions, an engineering assessment shall be conducted.

Fluid Service Factors may be applied to the product based upon local regulations and user requirements and are beyond the scope of this document. Guidelines for FSFs are presented in Annex D.

#### 5.3.2.4 Permissible Failure Modes

The permissible mode of failure shall be tensile rupture of the reinforcement.

If there is a failure mode other than the permissible mode during qualification testing, then that test result shall be discarded in computing averages or plotting the data.

NOTE An example of a non-permissible failure mode is ejection of the pipe from the fitting or coupling.

### 5.3.3 Establishing Short-term Burst Characteristics for QA

If burst test is used for QA testing as detailed in 6.4, determination of short-term burst properties is required to establish baseline burst strength of a product family.

Sets of short-term burst pressure results for the PFR and PVs shall be obtained following ASTM D1599,

Procedure A, using at least five specimens per set.

The 97.5 % lower prediction bound of each set of burst specimens shall be calculated using the Student's t-distribution. Refer to Annex H for the 97.5 % lower prediction bound calculation methodology.

The permissible mode of failure shall be tensile rupture of the reinforcement.

The duration of the test may be extended to accommodate larger diameter and higher pressure products and commonly available pressurization equipment. The test duration range used shall be a multiple of the range prescribed in ASTM D1599. The test duration range used shall be included in the qualification report and the same duration range shall be used for QA testing.

Preconditioning of specimens for short-term burst characteristics is not required. If preconditioning is used for establishing short-term burst characteristics the same preconditioning shall be used for QA testing.

### 5.3.4 Determination of MPR of Non-metallic Reinforced Pipe PVs

#### 5.3.4.1 General

The manufacturer shall be required to test all PVs within each product family to demonstrate that the PVs indeed belong in the family. Field-fittings shall be used for PV testing.

#### 5.3.4.2 Qualification of Product Variants Requiring a Two-specimen Test

A minimum of two specimens of each PV shall be subjected to a 1000-hour constant pressure test to demonstrate that the PV performs at least as well as the fully qualified product. Testing shall be in accordance with ASTM D1598 or ISO 1167-1 at the qualification test temperature. Both specimens shall not fail before 1000 hours. If one or both specimens fail before 1000 hours retesting shall be in accordance with 5.5. Failure to pass retest shall require full qualification testing.

Selection of the test pressure for the 1000-hour constant pressure test for the PV shall be directly proportional to the 1000-hour LPL intercept pressure of the PFR and calculated as follows:

$$P_{PV1000} = P_{PFR1000} \times (NPR\_PV / NPR\_PFR) \quad (2)$$

NOTE Additional guidance on scalability of fiber reinforcements is provided in Annex C.

### 5.3.5 Elevated Temperature Test

#### 5.3.5.1 General

An elevated temperature test procedure shall be employed to ensure that failure modes relating to polymeric components of the pipe within the end-fitting or coupling do not occur at times between the end of the regression test period and the end of the design life.

The elevated temperature test shall be made on PVs from each product family in accordance with Tables 3 and 4. Consideration should be given to the effect of dimensional tolerances at intermediate diameters

#### 5.3.5.2 Elevated Temperature Test Procedure

The manufacturer shall subject test specimens, with unrestrained field end-fittings or couplings, to a constant pressure test at a temperature in excess of the MAOT as follows:

$$\Delta T = \frac{1}{\alpha} log\left(\frac{t_{DesignLife}}{t_{Test}}\right) \quad (4)$$

where:

| | |
|---|---|
| $\alpha$ | is the time-temperature shift factor |
| $t_{\text{Design Life}}$ | is the design life time (hours) |
| $t_{\text{Test}}$ | is the test time (hours) |
| $\log$ | is log base 10 |
| $\Delta T$ | is the test temperature minus the product's MAOT. |

The test temperature shall not cause permanent changes to the material properties. For products with polyethylene materials in accordance with Table 1, the test duration shall be calculated using $\alpha$= 0.112 decades/°C. For other polymers, multilayer liners or covers constructed of two or more different materials, or for failure modes other than ductile, a value for alpha shall be determined, or a default value of 0.05 decades/°C assumed.

For steel-reinforced pipe the minimum test pressure shall be 1.5× the NPR. For nonmetallic reinforced products the minimum test pressure shall be the LCL at the RCRT. The minimum test time shall be that calculated using the formula above (Eq. 4). The inside environment for the pipe test specimen shall be water. The outside environment shall be air or a controlled temperature water bath. Other media may be used but the environment shall be given in the test report. The test fluid and the outer pipe wall shall be maintained within ±5 °F (±3 °C) of the test temperature. For failed tests the manufacturer shall confirm the failure mode is not brittle. Brittle failure mode is not allowed and shall be resolved before repeating this test. Retesting shall be in accordance with 5.5.

EXAMPLE 1 If $t_{\text{Design Life}}$ = 175,000 hours, $\alpha$ = 0.112, and a test time of at least 1000 hours is desired, then the test temperature shall be 36 °F (20 °C) greater than the product's MAOT.

EXAMPLE 2 Assuming the conditions of Example 1, if a test temperature 45 °F (25 °C) greater than the MAOT is to be used, then the test duration is at least 277 hours.

For each fitting or coupling type to be qualified at least two end-fittings or couplings shall be tested and the length of the spool piece between the two shall be as in 5.3.1.1 or 5.3.2.1 as applicable. All specimens shall survive without leakage for the full test period.

Following the elevated temperature test each test specimen shall be depressurized and stored at ambient for at least 24 hours in air. The test specimens shall then be pressurized to 150 psi ±50 psi (1.0 MPa ±0.34 MPa) at ambient temperature and examined for leakage. There shall be no visible leakage over a 24-hour period. Ambient temperature shall be monitored and recorded to aid in interpretation of pipe internal pressure changes.

### 5.3.6 Temperature Cycling Test Procedure

The manufacturer shall specify the allowable temperature cycling range and conduct each test in the sequence described below:

a) condition the pipe and the end fitting to steady state at the end-fitting's lowest allowable installation temperature and maintain for a minimum of 2.5 hours;

b) at this temperature, install the fittings in accordance with the manufacturer's written instructions.

c) condition the test specimen to steady state at the MAOT and maintain for a minimum of 2.5 hours;

d) condition the specimen to steady state at the specified lower test temperature (MAOT minus

allowable temperature cycling range) and maintain for a minimum of 2.5 hours;

e) repeat steps b and c for a total of three cycles;

f) condition the specimen to the ambient temperature and maintain for a minimum of 2.5 hours;

g) perform a leak test at a minimum pressure of 1.5× the NPR for a minimum of two minutes at ambient temperature. There shall be no leakage in two minutes to pass this test.

NOTE The maximum and minimum installation temperature can be different than the maximum and minimum operating temperature

### 5.3.7 Rapid Decompression Testing of Pipe Structure for Gas or Multiphase Service

Rapid decompression testing shall be performed on the PFR and a PV with the highest pressure rating in accordance with the laboratory test method outlined in Annex B. There shall be no collapse, disbondment, blistering, and/or cover blow off.

For pipes not intended for gas or multiphase service this clause does not apply and the pipes shall be marked indicating that gas service and multiphase service is not permitted. (See 7.2.1.1.g)

### 5.3.8 Minimum Bend Radius/Respooling Test

#### 5.3.8.1 Confirmation of Operating MBR

The operating MBR shall be specified by the manufacturer. This MBR shall be confirmed by:

- nonmetallic reinforced pipe shall be subjected to 1000-hour testing in accordance with 5.3.4.2
- steel reinforced pipe shall be short-term burst tested in accordance with 5.3.1.5 using two test specimens of steel reinforced pipe; each burst pressure shall be greater than or equal to $MPR/F_d$.

The specimens shall be tested by being held in a suitable fixture and maintained at the operating MBR during the test. Retesting shall be in accordance with 5.5.

#### 5.3.8.2 Confirmation of Handling MBR < Operating MBR

If the handling MBR is smaller than the operating MBR, precondition the specimens to the handling MBR and perform the test in 5.3.8.1 at the operating MBR. If the handling MBR is equal to or greater than the operating MBR, test 5.3.8.1 satisfies this requirement. If unsuccessful, all specimens shall be preconditioned to the handling MBR prior to performing MPR determination tests for the PFR qualification testing to 5.3.1 for steel reinforced pipe or 5.3.2 for nonmetallic reinforced pipe.

#### 5.3.8.3 Effects of Handling and Spooling

The effect of handling and spooling on the pipe performance (MPR) shall be demonstrated by preconditioning two PFR specimens with 10 bending cycles to the operating MBR. After preconditioning the specimens shall be subjected to a burst test in accordance with 5.3.1.5 for steel reinforced pipe or a 1000-hour test in accordance with 5.3.4.2 for nonmetallic reinforced pipe to demonstrate that the pipe performance has not been negatively affected by preconditioning. Retesting shall be in accordance with 5.5.

If the handling MBR is smaller than the operating MBR, one of the ten conditioning cycles shall be conducted at the handling MBR.

If this test (or the retest) is unsuccessful or if the manufacturer prefers, pipe specimens for full qualification

as a PFR shall be conditioned with 10 bending cycles at the operating MBR.

#### 5.3.8.4 Respooling Preconditioning

If respooling is allowed, precondition two PFR specimens to the manufacturer's stated number of allowable bending cycles to the applicable respooling MBR and confirm by means of a burst test in accordance with 5.3.1.5 for steel reinforced pipe or a 1000-hour test in accordance with 5.3.4.2 for nonmetallic reinforced pipe. Retesting shall be in accordance with 5.5.

If the allowable number of respooling cycles is equal to or greater than 10 and the respooling MBR is less than or equal to the operating MBR, the requirements of 5.3.8.3 are satisfied by this test.

If this test (or the retest) is unsuccessful, all specimens shall be preconditioned to the respooling MBR prior to performing PFR MPR determination testing to 5.3.1 for steel reinforced pipe or 5.3.2 for nonmetallic reinforced pipe.

### 5.3.9 Axial Load Capability for Installation

The manufacturer shall specify the maximum allowable axial tension load on the pipe for each PV and confirm by testing as follows. If the manufacturer's recommendations for installation involve pulling on pipe that already has end-fittings and/or couplings attached, the manufacturer shall conduct this test on the assembled pipe body with end-fittings and/or couplings.

Two samples for each design per Tables 3 and 4 shall be subject to failure tension testing. The allowable axial tension load shall be no greater than 50% of the lowest measured failure tension or calculated failure tension for PV's.

Then, one of the following test procedures shall be used to confirm the axial load capability for installation:

a) Two specimens shall be conditioned at the allowable axial tension load with no internal pressure for 1 hour minimum followed by 1000-hour testing in accordance with 5.3.4.2 for nonmetallic reinforced pipe. For steel reinforced pipe, two test specimens shall be short-term burst pressure tested in accordance with 5.3.1.5 and each burst pressure shall be greater than or equal to $MPR/F_d$.

b) Two specimens shall be conditioned at the allowable axial tension load with no internal pressure for a minimum of 1 hour. The target axial tension load shall be achieved in no less than 1 minute and no more than 20 minutes. The two specimens shall then be burst tested per 6.4.2.2.

Retesting shall be in accordance with 5.5.

### 5.3.10 External Load Performance

External load performance shall be characterized on the largest diameter lowest pressure PV using ASTM D2412.

### 5.3.11 Lowest Allowable Operating Temperature (LAOT) Test

The manufacturer shall specify the lowest allowable operating temperature and validate it with this test. Only field-fittings qualified by the pipe manufacturer shall be used for this test.

a) condition the specimen until it reaches steady state at the minimum allowable operating temperature and maintain for a minimum of 2.5 hours;

b) perform a pressure leak test at MPR and at the minimum allowable operating temperature for a minimum of 60 minutes;

c) an additional pressure leak test shall be performed at 150 psi ±50 psi (1.0 MPa ±0.34 MPa) and at the minimum allowable operating temperature for a minimum of 10 minutes to assure the low pressure leak tightness of the connection;

d) gas or liquid may be utilized as the pressurizing medium; and

e) all specimens shall survive without leakage for the full test period.

### 5.3.12 Impact Resistance

The manufacturer shall quote the impact energy resistance of the pipe at minimum installation temperature. Two pipe specimens shall be impacted according to the applicable sections of ASTM D2444 using Tup B or an equivalent test method. Following impact testing, the impact energy resistance of the pipe shall be confirmed by means of 1000-hour testing in accordance with 5.3.4.2 for nonmetallic reinforced pipe. If the manufacturer can demonstrate that the 1000-hour test and quick burst test yield the same result on the PFR through testing, the short term burst test may be used on the PVs. For steel reinforced pipe, the two test specimens shall be short-term burst pressure tested in accordance with 5.3.1.5-and each burst pressure shall be greater than or equal to $MPR/F_d$. Retesting shall be in accordance with 5.5.

Following impact testing, the cover shall not have been breached.

### 5.3.13 Thermal Expansion Coefficient

The manufacturer shall measure and quote the axial thermal expansion coefficient of the pipe measured over a temperature range of at least 50 °F (28 °C). The pipe test specimen shall be a minimum length of 6× the nominal pipe diameter. Pipe test specimens may be pre-conditioned. Measurements shall be conducted unpressurized and at the NPR. For applications where OD clearance is critical the hoop thermal expansion coefficient shall also be determined.

NOTE: Preconditioning may affect the thermal expansion coefficient for some designs.

### 5.3.14 Growth and Shrinkage on Application of Pressure

The manufacturer shall measure and quote changes in pipe length and diameter which take place as the pipe is pressurized from ambient pressure up to and including expected field hydrotest pressure. The quoted changes should be representative of the changes likely to be observed in the field in an unconstrained condition. The pipe test specimen shall be a minimum length of 6x the nominal pipe diameter.

### 5.3.15 Chemical Resistance of Pipe Assembly

The manufacturer shall perform an engineering assessment on the entire system (pipe and fitting) to demonstrate its suitability for common oil and gas applications. This assessment shall be supported by one or a combination of:

- Documented field experience of at least 3 years or,

- Fluid and chemical resistance lab tests on pipe and fittings simulating the combined effect of the operating field conditions and,
- The chemical resistance testing required in Section 4.

If the end-user requires additional lab testing on pipe sections, then the test protocol should be defined in an agreement between the pipe manufacturer and the user.

## 5.4 Requalification

Requalification shall be required when the manufacturer makes changes to the materials and/or manufacturing process used in any product family. Use of thermoplastic liner/cover materials from the same or different suppliers that have the same ASTM material cell classification shall be evaluated and technically justified in accordance with Table 5. Variations in formulation that do not affect the cell classification shall be confirmed to have equivalent or better performance to the originally qualified material.

Material changes in accordance with Table 5 shall be accompanied by a technical justification of the effect of the change. In addition, the following requirements apply:

- The technical justification shall include documented consideration of whether the change would adversely affect the results of any of the qualification tests required by this specification; if this cannot be determined by analysis, the relevant qualification tests shall be repeated in addition to the partial requalification.
- For nonmetallic reinforced pipe, partial requalification according to Section 12 of ASTM D2992-18 except that the distribution of hours to failure shall be a minimum of three points between 100 hours and 999 hours for one set, and minimum of three points greater than 2000 hours for the second set.
- For steel reinforced pipe, MPR determination according to 5.3.1.6.
- If specimens fail to pass the reinforcement material specific test, the manufacturer may choose to retest in accordance with 5.5. If the retest specimens fail to pass, the changes shall require full qualification according to 5.2.

Changes to the liner or cover as described in Table 5 shall also require accelerated life testing of the end-connection system in accordance with 5.3.5 as a minimum. Color changes are Acceptable Changes with Technical Justification (including chemical compatibility with the new color) and Partial Requalification.

A fully qualified product produced on a portable factory that has a quality management system in accordance with 6.1 established for on-site manufacturing and set-up shall not be considered to have a change in its manufacturing process simply as a result of its factory having been moved.

Changes not described in Table 5 shall be subject to full qualification according to Section 5.2.

**Table 5—Summary of Acceptable Changes with Technical Justification and Partial Requalification**

| | |
|---|---|
| Liner/Cover | Any change in the qualified polymer compound except by replacement with the same compound from a different vendor.<br><br>Color changes<br><br>A design change in thickness of liner or cover.<br><br>Compounds not part of the PFR qualification process shall also be tested in accordance with 5.3.5, 5.3.12, 5.3.13, and 5.3.14, unless specifically exempt by the technical justification. |

| | |
|---|---|
| Reinforcement | Material supplier<br><br>Supplier's grade and specification Filament diameter<br><br>Tow size/configuration |
| Reinforcement Matrix and Adhesives | Material supplier grade<br><br>Thermoset curing system manufacturer and thermoset curing system grade<br><br>Thermoset Tg |
| Manufacturing | Transfer of manufacture from one plant to another or additional manufacturing lines or locations.<br><br>Transfer from prototype to equivalent commercial production manufacturing. |

### 5.5 Retest Procedure

A qualification test with pass/fail criteria may be subject to this retest procedure.

If one or more of the original test specimens fail to conform to any of the specified requirements for a particular test, the manufacturer may elect to make retests. For each original non-conforming specimen two additional replicate specimens shall be made from the same batch and tested. If all the retest specimens conform to all specified test requirements, the retesting is successful and the original test requirements are met. The cause of the initial failure shall be determined and documented in the test report.

If any retest specimen fails to conform, the specified requirements have not been met.

## 6 Process and Quality Assurance Requirements

### 6.1 Quality Management System

Products meeting this specification shall be manufactured in a facility that maintains a written quality management system in accordance with API Q1, ISO TS 29001, or ISO 9001.

### 6.2 Extruded Polymer Layers

Materials for use in extruded polymer layers shall have a Certificate of Conformance to the specification from the resin manufacturer or shall be tested and documented by the pipe manufacturer to verify compliance with the specification.

Extrusion of thermoplastic material shall be performed in accordance with the manufacturer's documented procedures. Each extrusion shall be controlled in accordance with an approved setup sheet that provides settings for all essential variables based on the material and sizing of the product.

The liner shall be free of holes or other defects that could cause a leak or prevent containment of the intended fluids.

### 6.3 Reinforcement

#### 6.3.1 Steel Reinforcement

Steel reinforcement materials for use in pipe shall have a Certificate of Conformance to Table 4 from the reinforcement manufacturer, or shall be tested and documented by the pipe manufacturer to verify compliance with Table 4.

The specification shall, as a minimum, include required values and tolerances for chemical composition, mechanical, and physical characteristics detailed in Table 4.

**Table 4—Steel Reinforcement Property Requirements**

| Test | Method | Frequency |
|---|---|---|
| Chemical Composition | ASTM A751 or equivalent | One per batch |
| Tensile Test | ASTM A370 or equivalent | Two per coil[1] |
| Dimensions | | Two per coil[1] |

[1]A coil is a continuous length of steel reinforcement from the same forming process and heat treatment batch. If intermediate welds used to join coil sections for transport have been qualified by the subcontractor in accordance with the manufacturer's procedures, these welds may be kept during winding onto the pipe. If these welds have not been qualified, they shall be cut out of the coil during the winding of the pipe.

#### 6.3.2 Nonmetallic Reinforcement

Each lot of nonmetallic reinforcement material shall be tested to verify that the properties of the reinforcement meet the requirements of the applicable material specification in 4.2.2.3. In cases where the reinforcement supplier provides a Certificate of Conformance, that certificate shall show the actual measured values for each test.

### 6.4 Quality Assurance Tests

#### 6.4.1 General

Any purchaser has the option to verify product performance and may request a product specimen be taken and have that specimen performance tested in addition to the requirements of this section.

For the purposes of this section, welds or reinforcement joining practices shall be considered to include only those where greater than 1 % of the total reinforcement cross-sectional area is affected at any point along the pipe. The manufacturer shall carry out at least one of the following QA tests:

a) for steel reinforced pipe with welds or reinforcement joining practices greater than 1 %, hydrostatic testing in accordance with 6.4.3;

b) for steel reinforced pipe with welds or reinforcement joining practices less than 1 %, hydrostatic testing in accordance with 6.4.3 or batch testing in accordance with 6.4.2;

c) for nonmetallic reinforced pipe with welds or reinforcement joining practices less than 1 %, batch release tests in accordance with 6.4.2; or

d) for nonmetallic reinforced pipe with welds or reinforcement joining practices greater than 1 %, batch release tests in accordance with 6.4.2 or hydrostatic testing in accordance with 6.4.3.

#### 6.4.2 Batch Release Tests

##### 6.4.2.1 General

Two specimens of pipe per batch (one cut off from each end) shall be tested.

Two options are available for batch pressure testing: (1) the short-term burst test or (2) the constant pressure test. Reusable end-fittings, different in design to those used in the field, may be employed for these tests.

##### 6.4.2.2 Short-term Burst Test

The short-term burst test shall follow ASTM D1599, Procedure A or Procedure B, except that the pressurization rate shall be the same as that used in 5.3.1.5, or 5.3.3. End closures shall be unrestrained.

For steel reinforced pipe, each test specimen's short-term burst pressure shall be greater than or equal to $MPR/F_d$.

For nonmetallic reinforced pipe, each test specimen's short-term burst pressure shall be greater than or equal to 90 % of the 97.5 % lower prediction bound value as calculated in 5.3.3.

If one (but not both) of the specimens fails this batch test by having a burst pressure lower than the product's baseline value the retest procedure of 6.4.2.4 shall be used. If both specimens fail this batch test, the batch shall be rejected.

#### 6.4.2.3 Constant Pressure Test

Alternatively, a constant pressure test may be employed with the test period chosen as either 1 hour or 10 hours and performed at the qualification test temperature. The pressure level shall be chosen as the LPL pressure corresponding to 1 hour or 10 hours from the regression curve. Testing shall be in accordance with ASTM D1598 or ISO 1167-1.

The length of time of the test shall be chosen to coincide with a region of the regression curve where sufficient experimental points are available to ensure accuracy.

If one (but not both) of the specimens fails to pass this batch test, i.e. the time to failure is lower than the corresponding LPL value, the retest procedure stipulated in 6.4.2.4 shall be used. If both specimens fail this batch test, the batch shall be rejected.

#### 6.4.2.4 Retest Procedure

If a single specimen fails to conform to any of the above specified requirements, the manufacturer may elect to make retests on two additional replicate specimens from the same batch. The batch shall be accepted if both of the retest specimens conform to the requirements. The batch shall be rejected if either retest specimen fails to conform.

### 6.4.3 Hydrostatic Test

The nominal hydrostatic test pressure shall be a minimum of 1.3× the NPR, and shall be applied to the entire manufactured pipe length. Unless otherwise specified, e.g. for cold weather testing, potable water should be used for the test fluid. Water quality should be assessed versus any limitations provided by end-fitting metallurgy. A suitable dye may be added to assist in leakage detection. The test may be carried out with the pipe coiled on a drum. Trapped air shall be removed from the pipe in accordance with the manufacturer's procedures. Safety procedures shall take account of the very high strain energy stored in this type of product. Field end-fittings are not required to be used for this hydrostatic test.

The pressure should be gradually increased, at a rate not greater than specified in the manufacturer's test procedure, to no greater than 110% of the nominal test pressure and constant volume maintained until the pressure stabilizes. The pressure shall be considered stabilized when the pressure drop is less than 5% in a 1-hour period. Pressure should then be increased to between the nominal test pressure and 110% of the nominal test pressure and maintained for a minimum of one hour during which time there shall be no leakage or other signs of deterioration. Alternative test procedures are acceptable if agreed between the purchaser and the manufacturer. If the test is not successful, the pipe shall enter a nonconformance review by the manufacturer. Either the pipe shall be rejected, or the cause of the nonconformance shall be remedied and the pipe retested.

Depressurization shall be performed at a rate in accordance with the manufacturer's test procedure. After depressurization the end-fitting areas shall be visually examined for any sign of damage or leakage from both the pipe and the end-fittings or couplings. Procedures should remove as much water as possible from the pipe after completion of the test.

# 7 Dimensions, Tolerances, and Marking

## 7.1 Dimensions

The nominal diameter for all sizes 3 in. and greater shall be in half-inch increments and the minimum allowable inside diameter shall be no smaller than nominal diameter minus $^1/_2$ inch, as demonstrated in the example shown in Table 5. Below 3 in. nominal diameter, the minimum allowable inside diameter shall be no smaller than nominal diameter minus $^1/_4$ in.

The manufacturer shall document both the internal and external diameter of the pipe.

**Table 5—Sizing in Accordance with Nominal Diameter**

| Nominal Diameter (in.) | 2 | 2.5 | 3 | 3.5 | 4 | 4.5 | 5 | 6 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| Minimum ID (in.) | 1.75 | 2.25 | 2.5 | 3.0 | 3.5 | 4.0 | 4.5 | 5.5 | 7.5 |

For products manufactured according to this specification, iron pipe size equivalents in the top row of Table 5 are based on the minimum ID in the second row of Table 5. Other sizes, including sizes larger than 8 inches, are acceptable.

The manufacturer shall specify and document the tolerances to be used for the outside diameter of the pipe and for the thickness of each layer of the pipe. These tolerances shall be verified in the design process to be acceptable such that the performance of the individual layers and pipe are unaffected by variations within the specified tolerances.

## 7.2 Marking

### 7.2.1 Pipe Marking

#### 7.2.1.1 General

The following information shall be printed on the outside surface of the pipe:

a) this API 15S designation;

b) spoolable pipe manufacturer name or trademark;

c) unique identification code for traceability that includes the manufacturing location and date of manufacture;

d) nominal pipe size with units;

e) nominal pressure rating with units, or class, or other designation, and;

f) MAOT at the NPR.

g) Additional markings are permitted.

#### 7.2.1.2 Other Criteria

The following criteria apply to all required markings:

a) they shall be repeated at intervals not exceeding 3 ft (1 m);

b) they shall have a minimum character height of 1/4 in. (6 mm); and

c) they shall remain legible and visible after normal handling and installation practices.

For indented printings, either the indented print line shall be in a color that contrasts with that of the pipe or a separate print line shall be in a color that contrasts with the pipe.

#### 7.2.2 Fittings Marking

All fittings shall be marked with the following information:

a) spoolable pipe manufacturer name or trademark;

b) unique identification code for traceability that includes reference to manufacturing location and date of manufacture; and

c) nominal pipe size with units and/or the identification of pipe the fitting is to be used with.

Additional markings are permitted.

### 7.3 Packaging

Manufacturer's procedures shall include packaging requirements for pipe and field-fittings prior to leaving the manufacturing facility including but not limited to:

a) assurance that the handling MBR is not violated;

b) protection at pipe ends to prevent water ingress and UV damage at pipe terminations, and to keep out unwanted objects;

c) method to secure the pipe to the reel, coil or attached supports;

d) protection of the field-fittings from damage and corrosion during transport.

## 8 Documentation

### 8.1 Certification of Conformance

The manufacturer shall have available certification that the product was manufactured and tested in accordance with this specification.

### 8.2 Quality Assurance Test Reports

The manufacturer shall have available a report which documents the results of quality assurance tests in accordance with 6.4.

### 8.3 Record Retention

The manufacturer shall keep on file for 10 years all documentation pertaining to the pipe manufacture, including manufacturing records, certificates, inspection, and quality assurance test documentation.

### 8.4 Qualification Test Report

The manufacturer shall prepare qualification test report(s) demonstrating conformance to this specification and they shall be made available for review on request.

The qualification test report(s) shall include description of test specimen type (i.e. PFR, PV, component material, assembly), test method, and final test results on the qualified product at the specimen level (quantitative or pass/fail).

### 8.5 Project Information Checklist

Guidance for information that may be provided by the purchaser for a project is provided in Annex A.

### 8.6 Transportation, Storage, Installation, and Maintenance Guidance

Guidance for information that may be provided to the purchaser for transportation, storage, installation and maintenance is provided API 15S-IH.

# Annex A
(informative)

# Project Application Information

The purchaser should provide the following information to the manufacturer or distributor with all purchase orders.

| | |
|---|---|
| **Basic Design Data** | |
| Bore Diameter, inches or millimeters | |
| Pipeline Length, feet or meters | |
| Anticipated Service Life, years | |
| Max/Min Design Temperature, °F or °C | |
| Normal Operating Temperature, °F or °C | |
| Max/Min System Design Pressure | |
| Normal and Maximum Operating Pressures | |
| Pressure Fluctuations (size and frequency) | |
| External Pressure | |
| Soil Loading | |
| Thermal Insulation Requirements | |
| End-fitting and Connector Metallurgy | |
| **Fluid service** | |
| Gas/Water/Oil/Multiphase (Please specify) | |
| Production/Injection (Please specify) | |
| Fluid Composition including aromatic content | |
| $CO_2$/$H_2S$ Content | |
| Solids Content | |
| Other fluids, e.g. production chemicals | |
| **Quality assurance** | |
| Required Batch and Hydrotest Procedures | |
| **Operational requirements** | |
| Inspection Requirements – internal/external | |
| Pigging Requirements | |
| Reparability Requirements | |
| Impact Resistance Requirements | |
| External Wear Requirements | |
| **Installation details** | |
| Description of Installation (above/below ground) | |
| Ground Conditions | |
| External Environment (temperature, sun, etc.) | |
| External Interference Hazards | |
| Installation Procedure | |
| Routing and Spatial Limitations | |
| Future Tie-in Requirements | |
| Delivery/Shipping Instructions | |
| End-fitting Interface Requirements | |
| Min/Max Ambient Temperature | |

# Annex B
(normative)

# Pipe Blowdown Test Procedure

In gas or multiphase service, gases will diffuse through the liner and may accumulate at interfaces within the pipe structure. This local accumulation may result in liner collapse, material blistering, multilayer disbondment, or cover rupture. This test should simulate the worst-case interface pressure buildup in a field application.

This test should simulate the worst-case interface pressure buildup in a field application. Testing shall be by the following method.

## B.1 Pipe Specimen Preparation

**B.1.1** At least one specimen shall be tested and shall be traceable to a production run, which shall have passed all QA requirements.

**B.1.2** Each specimen shall be uniquely identified with a laboratory specimen number, traceable to the production run.

**B.1.3** Specimen length shall be in accordance with Section 5 of this document.

## B.2 Test

**Warning—Fluids under high pressure can be dangerous. It is the responsibility of laboratory personnel to utilize proper safety procedures in handling and testing.**

**B.2.1** Attach end-fittings to the specimen according to standard assembly practices.

**B.2.2** Install the specimen in the appropriate equipment for temperature generation and pressure containment. Fill the specimen with high pressure gas and increase the temperature to the maximum design temperature and the pressure to the highest nominal pressure rating. If the manufacturer applies an $F_{Sn}$ for gas service, the test shall be at NPR × $F_{Sn}$. The high-pressure gas selected shall be relevant to the purpose of the test and to the pipeline application under consideration; the test gas composition shall be documented in the test report. The gas shall not condense to a liquid during the test procedure.

NOTE Testing may be conducted following soaking in a liquid hydrocarbon solution.

**B.2.3** Adjust the equipment until the pressure and temperature is stabilized. The hold period shall be such as to achieve steady state permeation through the liner. During the hold period, maintain the pressure and temperature.

**B.2.4** Upon completion of the hold period, rapidly remove pressure from the specimen. Rate of depressurization shall not be less than 2MPa (290 psig) per minute.

**B.2.5** Remove the specimen from the equipment and remove the end-fittings. Visually examine the pipe specimen for cover rupture and liner collapse. Dissect the specimen and visually inspect for evidence of disbondment between layers and blistering. Record the results of testing.

# Annex C
(informative)

# Scaling the test pressure for a Product Variant from the Product Family Representative

The 1000-hour constant pressure test for the PV shall be directly proportional to the 1000-hour LCL intercept pressure of the PFR.

The hydrostatic strength of a reinforced pipe is mainly brought about by the reinforcement layer. The thermoplastic liner and cover do not contribute significantly. This is because the modulus of the reinforcing material is very much higher than the modulus of the thermoplastic liner and cover material. As a consequence, the stresses in the pipe wall concentrate in the reinforcement.

As a conservative estimate, it is assumed that the reinforcement layer is the only load bearing element in the pipe wall. The hydrostatic strength of the pipe can be expressed as follows:

$$P_{max} = C \times A/D^2 \qquad (C.1)$$

where:

C is a proportionality factor,
A is the minimum effective reinforcement layer cross-sectional area,
D is the reinforcement layer mean diameter.

The hydrostatic strength of the PV with respect to the PFR is then then given as follows:

$$P_{PV1000} = P_{PFR1000} \times (A_{PV} / A_{PFR}) \times (D^2_{PFR} / D^2_{PV}) \qquad (C.2)$$

In certain RTP pipe constructions, A (area) may be difficult to measure or define, in particular when reinforcement construction is not homogeneous, e.g. non-impregnated filaments or flat strips with gaps in-between.

Alternatively, for calculating the PV hydrostatic strength the following equations may be used may be used:

$$P_{PV1000} = P_{PFR1000} \times (W_{NPR\_PV}/W_{NPR\_PFR}) \times (D^2_{PFR}/D^2_{PV}) \qquad (C.3)$$

where:

W is the minimum total weight of the reinforcement layer per unit length of pipe for the NPR_PV and NPR_PFR;

$$P_{PV1000} = P_{PFR1000} \times (LD_{NPR\_PV}/LD_{NPR\_PFR}) \times (D^2_{PFR}/D^2_{PV}) \qquad (C.4)$$

where:

LD is the minimum total linear density of the fiber reinforcement for the NPR_PV and NPR_PFR;

or

$$P_{PV1000} = P_{PFR1000} \times (N_{NPR\_PV}/N_{NPR\_PFR}) \times (D^2_{PFR}/D^2_{PV}) \qquad (C.5)$$

where:

N is the minimum total number of filaments or fiber strands of equal linear density in the reinforcement layer.

# Annex D
(informative)

# Service Factors

The pipeline design engineer may select service factors after evaluating fully the service conditions and the engineering properties of the specific pipe product. Some of these service conditions are, but not limited to, cyclic, chemical aging, installation factors, degree of reliability selected, etc.

The MOP may be obtained by multiplying the NPR by application related service factors ($F_{Sn}$) as shown below:

$$MOP = NPR \times F_{S0} \times F_{S1} \times F_{Sn} \qquad \text{(D.1)}$$

Service factors ($F_S$) may be applied in addition to the design factor as defined in 5.2 and 5.3 and multiplied by the NPR to determine the MOP.

The intent of the $F_{fluid}$ is to provide additional protection based on consequence of failure and not fluid compatibility.

Guidelines for fluid, $F_S$ ($F_{fluid}$), are as follows:

a) use a $F_{fluid}$ of 0.67 or less for all gas services;

b) use a $F_{fluid}$ of 0.80 or less for all hydrocarbon liquid services;

c) use a $F_{fluid}$ of 1.0 or less for all water services;

d) multiphase services require individual evaluation to assess consequence of failure.

$F_s$ based on area classifications may be used instead of these factors. These will normally be applied based on agreement between the manufacturer and the owner of the pipeline or through local regulations.

# Annex E
(normative)

# Requirements for Cyclic Pressure Fluctuations

## E.1 Introduction

All applications of pressure have some expected level of cyclic pressure fluctuations. This can be in the form of on/off pump cycles, up/down strokes from a pump jack, high frequency pressure pulsations of positive displacement pumps (e.g. triplex pumps), or other services with known fluctuations in pressure. The following method is to be used to determine allowable cyclic operating regimes.

## E.2 Cyclic Loading Definition

Cyclic loading is defined as the following:

More than 7000 cycles with $\Delta P/NPR \geq 6$ %.

Products intended for cyclic service according to this definition shall be evaluated in accordance with F.3.

## E.3 Test Method

Cyclic regression testing may be completed on the pipe and field-fitting system or on the pipe reinforcement material as described below. If completed on the reinforcement material, the material loading shall be converted to pipe loading using a validated calculation methodology.

### E.3.1 Cyclic Fatigue Curve Test Method on Reinforcement Material Specimens

Fatigue curves for reinforcement materials shall be created using a suitable test method according to ASTM E466 for steel reinforcement, ASTM D3479 for non-metallic reinforcement, or equivalent.

In addition, testing of at least two pipe specimens with field-fittings at MAOT shall be completed and shown to be conservatively represented by the reinforcement material test results. This can be shown by testing two pipe specimens to the minimum 7000 cycle or a higher preselected number of cycles LPL intercept for non-metallic reinforcement or S-N lower bound intercept for metallic reinforcement. Both specimens shall not fail before the 7000 cycle or the preselected number of cycles intercept. Retesting shall be in accordance with 5.8. Failure to pass retest shall require full pipe cyclic regression testing.

Reinforcement material changes in accordance with Table 5 shall be accompanied by a technical justification of the effect of the change, together with partial requalification using the test method originally employed to generate the fatigue curve, and the data analyzed according to Section 12 of ASTM D2992-18, except that the distribution of average cycles to failure shall be a minimum of three points between 10,000 cycles and 100,000 cycles for one set and minimum of three points greater than 100,000 cycles for the second set.

Tests on reinforcement material shall be of similar construction to the reinforcement used on the pipe.

### E.3.2 Cyclic Fatigue Curve Test Method on Pipe Specimens

Regression analysis for the PFR requires a minimum of 18 points carried out at the MAOT and in accordance with ASTM D2992-18, Procedure A with the following exceptions:

a) Determination of Cyclic LTHS, HDB, and PDB, as in accordance with 7.1, 7.4, and 8.2 of ASTM

D2992-18 are not applicable;

b) the cycle frequency may be less than 25 cycles/minute for pipe specimens;

c) the 15 million cycle specimen may be omitted;

d) failure detection method in accordance with 3.1.2 of ASTM D2143-00 is not required;

e) apparatus should meet the functional requirements of Section 6 of ASTM D2143-00;

f) specimen length shall be in accordance with Section 5 of this document;

g) the provisions of 8.1 of ASTM D2143-00 are not required;

h) salt water is not required;

i) reinforcement material changes in accordance with Table 5 shall be accompanied by a technical justification of the effect of the change, together with partial requalification according to Section 12 of ASTM D2992-18, except that the distribution of average cycles to failure shall be a minimum of three points between 10,000 cycles and 100,000 cycles for one set and minimum of three points greater than 100,000 cycles for the second set; and

j) pipe specimens that have not failed after more than 1 million cycles may be included as failures in establishing the long-term cyclic hydrostatic strength or pressure.

### E.3.3 Service Factor

A service factor of no greater than 0.1 shall be applied to the number of cycles from the LCL of the cyclic regression analysis to determine the allowable number of cycles for the specific application.

EXAMPLE: An application requires the pipe to withstand one cycle per day for 20 years between zero and 80 % of the NPR of the pipeline. This cycle count and amplitude is compared against the regression analysis or Goodman diagram to ensure no failure to the pipe after 10 cycles per day for 20 years (factor of at least 10 on cycle count).

The manufacturer shall precondition at least two pipe specimens with field-fittings to the allowable number of cycles at the MAOT and conduct a short-term burst pressure test in accordance with 5.3.1.5 for steel reinforced pipe, or according to 5.3.3 for non-metallic reinforced pipe. The result of the test shall be reported in the product qualification report. This test is only required at one pressure which shall be taken between 10,000 and 1 million cycles along the established regression curve and shall not be required for all applications once established.

# Annex F
(informative)

# Regression Curve Terminology

Using the analysis method of ASTM D2992-18 Annex A1, test data for the PFR is used to construct the mean regression line, as well as the LCL and LPL curves (see Figure G.1). The LCL curve is constructed so that there is a 97.5 % probability that the pipe's actual mean pressure versus time-to-failure regression line falls above this curve. The LPL curve is constructed so there is a 97.5 % probability that a single test specimen's pressure will fall above this curve. Figure G.1 also shows the use of a design factor ($F_d$) and a $F_{Sn}$ to determine the MPR and the MOP – see 5.3.2. Manufacturers may choose to use reinforcement stress rather than pressure when constructing these curves.

A manufacturer may choose to develop additional regression curves at temperatures other than the original qualification test temperature. In accordance with PPI TR-3, the $LCL_{RCRT}$ at temperatures between two regression curves shall be based on the following equation:

$$S_T = S_L - \frac{(S_L - S_H)(\frac{1}{T_L} - \frac{1}{T_T})}{(\frac{1}{T_L} - \frac{1}{T_H})} \quad \text{(G.1)}$$

where:

$S_T$ = $LCL_{RCRT}$ at interpolation temperature (psi)
$S_L$ = $LCL_{RCRT}$ at lower temperature (psi)
$S_H$ = $LCL_{RCRT}$ at higher temperature (psi)
$T_T$ = interpolation temperature (K)
$T_L$ = lower temperature (K)
$T_H$ = higher temperature (K)

Steel reinforced pipe products do not exhibit viscoelastic behavior. Steel reinforced pipe products have traditionally used short-term strength properties to establish long-term performance. For example, a short-term burst test is generally completed in several minutes.

Nonmetallic-reinforced pipe products have traditionally used 10,000-hour regression strength testing to establish long-term performance.

Due to the different methods used to establish strength properties, the design factors for steel reinforced pipe products versus nonmetallic reinforced pipe products will also be established using different methods and yield different factors. The intent is to provide similar final product performance.

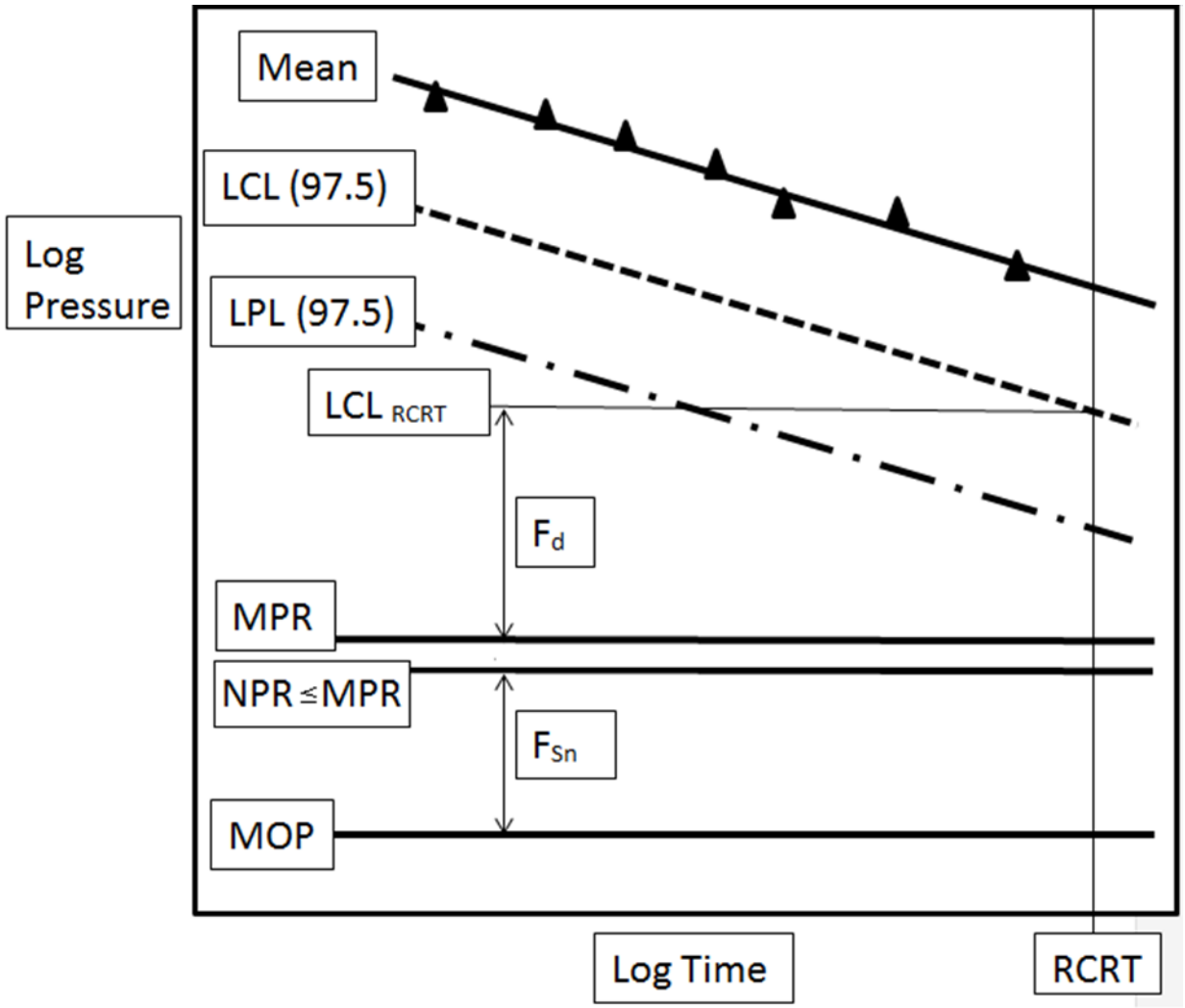


**Figure F.1 – Regression Curve, LCL Curve, LPL Curve, and Use of the $LCL_{RCRT}$ to Define MPR and MOP**

# Annex G
(normative)

# Information to be Provided by The Pipe Manufacturer

## G.1 Pipe Product Documentation

Manufacturer shall provide purchaser with the following information:

a) dimensions that include:
   1. pipe inside diameter;
   2. pipe outside diameter;
   3. pipe weight per unit length (empty and filled with water)
   4. field-fitting dimensions (outside diameter, length, field-fitting specification)
b) description of materials used in each layer of the product;
c) lowest allowable operating temperature (LAOT);
d) maximum allowable operating temperature (MAOT);
e) lowest and maximum temperatures allowed during field-fitting installation or maintenance operations;
f) nominal pressure rating (NPR);
g) maximum allowable external loading;
h) thermal expansion coefficient for pipe;
i) axial growth or shrinkage with application of internal pressure (up to 1.5x nominal pressure rating) and associated loads that may result;
j) maximum allowable installation axial tensile load capability with and without fittings;
k) operating, handling, and respooling MBRs;
l) minimum required length of straight pipe run from each coupler or end connection;

## G.2 Installation and Handling Information

If required by purchaser, manufacturer shall provide installation and handling guidance in accordance with API 15S-IH.

## G.3 Operational guidance

If required by the purchaser, the manufacturer shall provide the following operational guidance:

a) cyclic pressure operating guidance;

b) chemical compatibility;

c) rapid pressurization and depressurization guidance;

d) pigging;

e) winterizing and freezing;

f) heating or removal of ice or hydrate plugs;

g) fire resistance and post-fire repair criteria;

h) management of possible accumulation of permeated gases (e.g. in the pipe wall, at a vent hole, in the annulus, etc.) and associated hazards;

i) paraffin build-up;

j) visual inspection of in-service lines;

k) hydrostatic testing recommendations for maintenance or integrity management;

l) respooling, if allowed.

# Annex H
(normative)

# Lower Prediction Bound Calculation

The lower prediction bound shall be calculated using the mean and standard deviation of a previously obtained test data set as follows:

$$\text{Lower prediction bound} = \overline{x} - s\left[t_{(1-\alpha,n-1)}\sqrt{1+1/n}\right] \quad \text{(H.1)}$$

where:

$n$ = number of previously tested data points
$x_i$ = previously obtained test data values $(i = 1, n)$
$s$ = specimen standard deviation = $\left(\frac{\sum_{i=1}^{n}(x_i-\overline{x})^2}{n-1}\right)^{1/2}$
$\overline{x}$ = average of the previously obtained test data values
$t_{(1-\alpha,n-1)}$ = the 100(1-$\alpha$) percentile of the Student's t distribution with $n$-1 degrees of freedom

For purposes of this standard, α = 0.025 shall be used which leads to the 97.5 % lower prediction bound.

The values for the square bracketed factor involving $t$ and $n$ are tabulated in Table I.1. The value from the table shall be used when performing the calculation in accordance with Equation I1.

NOTE Equation I.1 is based upon the assumption that the data values are normally distributed.

**Table I.1 Tabulation of $\left[t_{(1-\alpha,n-1)}\sqrt{1+1/n}\right]$ for various values of $n$ with α = 0.025**

| $n$ | $\left[t_{(1-\alpha,n-1)}\sqrt{1+1/n}\right]$ | $n$ | $\left[t_{(1-\alpha,n-1)}\sqrt{1+1/n}\right]$ | $n$ | $\left[t_{(1-\alpha,n-1)}\sqrt{1+1/n}\right]$ |
|---|---|---|---|---|---|
| 5 | 3.041 | 26 | 2.099 | 47 | 2.034 |
| 6 | 2.777 | 27 | 2.093 | 48 | 2.033 |
| 7 | 2.616 | 28 | 2.088 | 49 | 2.031 |
| 8 | 2.508 | 29 | 2.083 | 50 | 2.030 |
| 9 | 2.431 | 30 | 2.079 | 51 | 2.028 |
| 10 | 2.373 | 31 | 2.075 | 52 | 2.027 |
| 11 | 2.327 | 32 | 2.071 | 53 | 2.025 |
| 12 | 2.291 | 33 | 2.068 | 54 | 2.024 |
| 13 | 2.261 | 34 | 2.064 | 55 | 2.023 |
| 14 | 2.236 | 35 | 2.061 | 60 | 2.018 |
| 15 | 2.215 | 36 | 2.058 | 70 | 2.009 |
| 16 | 2.197 | 37 | 2.055 | 80 | 2.003 |
| 17 | 2.181 | 38 | 2.053 | 90 | 1.998 |
| 18 | 2.168 | 39 | 2.050 | 100 | 1.994 |
| 19 | 2.156 | 40 | 2.048 | 120 | 1.988 |
| 20 | 2.145 | 41 | 2.046 | 150 | 1.983 |
| 21 | 2.135 | 42 | 2.043 | 200 | 1.977 |
| 22 | 2.126 | 43 | 2.041 | 300 | 1.971 |
| 23 | 2.118 | 44 | 2.039 | 600 | 1.966 |
| 24 | 2.111 | 45 | 2.038 | 1000 | 1.963 |
| 25 | 2.105 | 46 | 2.036 | ≥6300 | 1.960 |

REFERENCE Hahn, G. J. and Meeker, W. Q., *Statistical Intervals – A Guide for Practitioners*, John Wiley & Sons, Inc., 1991, p. 63

## Bibliography

[1] ASME BPVC, Section V, *Nondestructive Examination*

[2] ASTM C177, *Standard Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus*

[3] ASTM D570, *Standard Test Method for Water Absorption of Plastics*

[4] ASTM D1044, *Standard Test Method for Resistance of Transparent Plastics to Surface Abrasion*

[5] ASTM D1525, *Standard Test Method for Vicat Softening Temperature of Plastics*

[6] ASTM D1599, *Test Method for Resistance to Short-Time Hydraulic Pressure of Plastic Pipe, Tubing, and Fittings*

[7] ASTM D2143-00, *Standard Test Method for Cyclic Pressure Strength of Reinforced, Thermosetting Plastic Pipe*

[8] ASTM D4060, *Standard Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser*

[9] ASTM E831, *Standard Test Method for Linear Thermal Expansion of Solid Materials by Thermomechanical Analysis*

[10] ASTM E1269, *Standard Test Method for Determining Specific Heat Capacity by Differential Scanning Calorimetry*

[11] ASTM F412, *Standard Terminology Relating to Plastic Piping Systems*

[12] ISO 23936-2, *Petroleum, petrochemical and natural gas industries – Non-metallic materials in contact with media related to oil and gas production – Part 2: Elastomers*

[13] NACE TM0284-2011, *Evaluation of Pipeline and Pressure Vessel Steels for Resistance to Hydrogen-Induced Cracking*

[14] NORSOK M-710, *Qualification of non-metallic sealing materials and manufactures*

[15] PPI TR-4, *PPI Listing of Ratings for Thermoplastic Piping Materials or Pipe*

[16] PPI TR-19, *Chemical Resistance of Thermoplastics Piping Materials*

[17] Hahn, G. J. and Meeker, W. Q., *Statistical Intervals – A Guide for Practitioners*, John Wiley & Sons, Inc., 1991, p. 63