Spoolable Reinforced Plastic Line Pipe

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1 Scope

1.1 Coverage

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 with helically wrapped steel or nonmetallic reinforcing elements and an outer cover. The helical reinforcing elements shall be a 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 confined 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.

1.2 Application of the API Monogram

If the product is manufactured at a facility licensed by API and it is intended to be supplied bearing the API Monogram, the requirements of Annex A apply.

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

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

API Specification 15LE, *Specification for Polyethylene Line Pipe (PE)*, 4th Edition

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*

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

2 American Society for Testing and Materials International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428-2959, www.astm.org

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 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 D2513-14, *Standard Specification for Polyethylene (PE) Gas Pressure Pipe, Tubing, and Fittings*

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 D2992-12, *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 (?-N) Fatigue Data*

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

ASTM F876, *Standard Specification for Crosslinked Polyethylene (PEX) Tubing*

ASTM F2619-13, *Standard Specification for High-Density Polyethylene (PE) Line Pipe*

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 H2S-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/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*

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*

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

[4] National Association of Corrosion Engineers International, 1440 South Creek Drive, P.O. Box 218340, Houston, Texas 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.

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

3.1.4
coupling
Specific type of fitting developed for joining one section of pipe to another.

3.1.5
cover
Protective outer sheath of the pipe.

3.1.6
creep rupture
Failure as a result of a period under steady stress or pressure (also known as static fatigue).

3.1.7
cyclic loading
More than 7000 cycles and $\Delta P/NPR > 6$ % where ΔP is maximum to minimum amplitude.

3.1.8
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.

3.1.9
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.

3.1.10
disbond
Separation of the bonded layers.

3.1.11
end-fitting
A mechanical device that forms the transition from the pipe to the connector.

3.1.12
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.

3.1.13
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.

3.1.14
field-fitting
End-fitting or coupling designed for permanent installation.

3.1.15
function
Action(s) that an item is designed to perform.

3.1.16
laboratory test fitting
Used for testing to determine the properties of the pipe body.

3.1.17
liner
Continuous polymeric layer that is in contact with the conveyed fluid.

3.1.18
liner collapse
Movement of the liner away from the structural layer on reduction of internal pressure.

3.1.19
lower confidence limit
LCL
Hydrostatic pressure calculated for a specific time-to-failure using Formula A1.25 in ASTM D2992-12, replacing σy by σn in accordance with A1.4.6.4 in ASTM D2992-12.

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.

3.1.20
lower prediction limit
LPL
Hydrostatic pressure calculated for a specific time-to-failure using Formula A1.25 in ASTM D2992-12.

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

3.1.21
lowest allowable installation temperature.
Lowest allowable pipe temperature for deployment, e.g. unspooling

3.1.22
manufacturer
Entity that fabricates products according to this specification (and applies the monogram if a licensee).

3.1.23
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.

3.1.24
maximum operating pressure
MOP
Pressure obtained by multiplying the NPR by application related service factors.

3.1.25
minimum operating bend radius
Minimum allowable bend radius for the installed and pressurized pipe.

3.1.26
minimum respooling bend radius
Minimum allowable bend radius when respooling the pipe in the factory or the field.

3.1.27
minimum handling bend radius
Minimum allowable bend radius the unpressurized pipe is subjected to during any handling.

3.1.28
nominal pressure rating
NPR
Pressure rating of the pipe as defined by the manufacturer and does not exceed the MPR.

3.1.29
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.

3.1.30
product family representative
PFR
Product variant chosen for full qualification.

3.1.31
product variant
PV
Member of a product family with a specific pressure rating and diameter.

3.1.32
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.

3.1.33
qualified operator
An individual who has been evaluated and can perform assigned covered tasks and recognize and react to abnormal operating conditions.

3.1.34
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.

3.1.35
qualification test temperature
Temperature at which pressure tests are carried out to establish the MPR for non-metallic reinforced products.

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

3.1.36
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.

3.1.37
regression analysis
Statistical procedure to establish a design rating from pressure test results carried out over a long period of time, typically greater than 10,000 hours.

3.1.38
regression curve reference time
RCRT
Time of 175,000 hours that is used in this specification to define MPR.

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

3.1.39
reinforcing elements
The primary contributor to the hydrostatic strength of the pipe.

3.1.40
rupture
A tear, break, or fracture.

3.1.41
service life
Period of time during which the pipe fulfills all performance requirements.

3.1.42
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.

3.1.43
spoolable pipe
Pipe that is flexible enough to be spooled into a coil or onto a structural reel for transportation.

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

3.1.44
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.

3.1.45
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.

3.1.46
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 members.

3.1.47
tape
Reinforcement type in which the strength members are typically encapsulated in a matrix material and provided as a flat ribbon.

3.1.48
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
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 conform to the materials requirements listed within the standards listed in Table 1. Fitness for purpose shall be established based upon tests as specified in Table 2.

Master batch addition to the standard resin is acceptable as long as it is the same addition used to qualify the PFR.

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 maintain its integrity for the specified fluids under the given service conditions.

The final material properties after processing shall be within the acceptable range of properties developed during the qualification program in Section 5.

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 5.6 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.

PPI TR-19 may be used as a screening tool for evaluating fluid compatibility. ISO 23936-2 and NORSOK M-710 provide a methodology for performing fluid compatibility testing.

4.2.1.3 Blister Resistance

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}.

If the liner is a multilayer or coextruded structure, the adhesion between layers shall not be compromised during the blistering test.

Table 1—Polymer Material Standards

Polymer	Standard	Title
Polyethylene (PE)	ASTM D2513-14, Section 4 or ASTM F2619-13, Section 4 or API 15LE, 4th Edition, Sections 2 and 5.1.1 or ISO 4437-1:2014	*Standard Specification for Polyethylene (PE) Gas Pressure Pipe, Tubing, and Fittings* *Standard Specification for High-Density Polyethylene (PE) Line Pipe* *Specification for Polyethylene Line Pipe (PE)* *Plastics piping systems for the supply of gaseous fuels - Polyethylene (PE)*
All Polyamides (Nylons)	ASTM D6779	*Standard Classification System for and Basis of Specification for Polyamide Molding and Extrusion Materials (PA)*
PPS	ASTM D6358 ASTM D4067	*Standard Classification System and Basis for Specification for Poly (Phenylene Sulfide) (PPS) Injection Molding and Extrusion Materials Using ISO Methods* *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 ASTM D5857	*Standard Specification for Polypropylene Injection and Extrusion Materials* *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* 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 Extruded Polymers

Characteristic	Tests	Standard	Liner	Reinforcement Layer	Cover
Mechanical/Physical Properties	Resistance to Creep	ASTM D2990	X		X
	Yield Strength/Elongation	ASTM D638	X		X
	Ultimate Strength/Elongation	ASTM D638	X		X
	Stress Relaxation Properties	ASTM E328	X		X
	Modulus of Elasticity	ASTM D638	X		X
	Compression Strength	ASTM D695	X		X
	Impact Strength	ASTM D256	X		X
	Density	ASTM D792 or D1505	X		X
	Notch Sensitivity	ASTM D256	X		X
Thermal Properties	Brittleness (or Glass Transition) Temperature	ASTM D746 or ASTM E1356	X		X
	Glass Transition Temperature and Melting Point	ASTM D3418-12e1 or ISO 11357	X		X
Permeation Characteristics	Fluid Permeability	API 17J, 4th Edition Paragraph 6.2.3.2	X		X
	Blistering Resistance	API 17J, 4th Edition Paragraph 6.2.3.3	X		
Compatibility and Aging	Fluid Compatibility	See 4.2.1.2	X	X	X
	Aging Tests	See 4.2.1.2	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. 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 5.6 for additional information.

4.2.2.2 Steel Reinforcement Materials

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.

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 samples 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 sample has occurred.

4.2.2.2.4 Sour Service

4.2.2.2.4.1 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) specimens shall be loaded to at least 90 % of SMYS;

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

g) sample 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.

4.2.2.2.4.2 The test samples 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 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.

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 matrix, the glass fibers shall have a sizing that is compatible with the intended resin.

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 5.6 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 samples (minimum 18) used to qualify the product in 5.3.3. The T_g value of the thermosetting resin for QA/QC purpose should be established as:

a) the average T_g of all samples used to qualify the product components minus three standard deviations; and

b) minimum of 15 °C above the maximum rating temperature of the product when the T_g is measured by the on-set value of the DSC thermogram; or 20 °C when the T_g is measured by the on-set value of the storage modulus of the DMA curves.

The manufacturer shall verify that the samples used in the tests described in 5.3.4 and 5.3.5 meets 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.

4.2.3 Cover Materials

The cover material shall sustain its function for the manufacturer specified service conditions. Thermoplastic compounds shall conform to the requirements of the material standards listed in Table 1 and fitness for the purpose shall be established based upon tests as specified in Table 2.

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. Note: examples include solar radiation (UV) and wear resistance.

The cover shall meet the test requirements of 5.7.2 and 5.7.3.

Brittleness temperature shall be at or below the minimum design temperature when tested in accordance with ASTM D746.

Changes to the cover may require requalification—see 5.6 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.

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 samples 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 sample 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.

5 Qualification Program

5.1 General

Qualification requirements for the pipe bodies, end-fittings, couplers, 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, samples 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.

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

Unless otherwise specified, the test specimen length shall be in accordance with ASTM D1599. For nominal diameters eight inches and larger, shorter test specimens than what is prescribed in ASTM D1599 may be used if the manufacturer can show by technical means that the reduced length is justified.

5.2 Pressure Rating of Steel Reinforced Pipe

5.2.1 General

Steel reinforcement does not have significant regression properties. For this reason, the MPR shall be based on the calculated minimum burst pressure ($P_{burst, min}$) of the pipe in accordance with 5.2.5.

The MPR of the PFR and all product variants shall be confirmed by burst pressure testing in accordance with 5.2.3.3 and 5.2.5 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 samples, including any that fail by modes other than the PM, shall be reported in the qualification report.

5.2.2 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× the nominal pressure rating of the PFR. Size and/or pressure rating changes outside these ranges require full qualification as a new PFR in accordance with Section 5. 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 5.2.3 to determine properties for the product family.

5.2.3 Qualification of the Product Family Representative

5.2.3.1 Test Requirements

All qualification tests from 5.2, 5.4, 5.5, and 5.7 shall be carried out on spool pieces comprising the basic pipe body, together with one or more types of end-fitting.

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 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 5.4.3.

5.2.3.2 Preconditioning of Samples

The test samples shall either be preconditioned or shall pass the tests described in 5.5.2. If preconditioning is deemed necessary as in accordance with 5.5.2, the test samples 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 5.5.2) prior to performing PFR qualification testing.

5.2.3.3 Confirmation of MPR

The MPR of the PFR as calculated in 5.2.5 shall be confirmed by burst pressure testing on at least five specimens in accordance with 5.2.4. 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 J for the 97.5 % lower prediction bound calculation methodology.

5.2.3.4 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 nonpermissible failure mode is ejection of the pipe from the fitting or coupler.

5.2.3.5 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 samples 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.

5.2.4 Qualification of Product Variants

The manufacturer shall be required to test all PVs within each product family. All PVs shall be qualified by burst pressure testing on at least five specimens in accordance with 5.2.4. The 97.5 % lower prediction bound of the set of burst specimens shall be calculated using the Student's t-distribution. For the PV to be qualified, the calculated 97.5 % lower prediction bound shall be greater than or equal to MPR/Fd. Refer to Annex J for the 97.5 % lower prediction bound calculation methodology. The permissible failure modes shall be in accordance with 5.2.3.4.

5.2.5 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 F for guidance on other fluids);

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

c) installed in full compliance with manufacturer's recommendations and requirements (refer to Annex D for guidance on handling, installation and operation practices).

If operating conditions are outside these baseline conditions, additional testing or analysis shall be considered.

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 F.

5.3 Pressure Rating of Nonmetallic Reinforced Pipe

5.3.1 General

Nonmetallic reinforcement has significant regression properties. For this reason, the MPR shall be based on a design factor applied to the long-term hydrostatic pressure of the pipe.

The MPR of the PFR and all product variants shall be confirmed by long-term hydrostatic pressure testing in accordance with 5.3, 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 samples, including any that fail by modes other than the PM, shall be reported in the qualification report.

Long-term hydrostatic pressure shall be developed and reported adhering to the methodology of ASTM D2992-12, Procedure B.

5.3.2 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× of the nominal pressure rating of the PFR. Size and/or pressure rating changes outside these ranges require full qualification as a new PFR in accordance with Section 5. 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 5.3.3 to determine the regression slope for the product family.

5.3.3 Qualification of the Product Family Representative

5.3.3.1 Test Requirements

All qualification tests from 5.3, 5.4, 5.5, and 5.7 shall be carried out on spool pieces comprising the basic pipe body, together with one or more types of end-fitting.

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 may be used if the manufacturer can show by technical means that the reduced length is justified.

5.3.3.2 Preconditioning of Samples

The test samples shall either be preconditioned or shall pass the tests described in 5.5.2. If preconditioning is deemed necessary in accordance with 5.5.2, the test samples 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 5.5.2) prior to performing PFR qualification testing.

5.3.3.3 Determination of MPR

The MPR of the PFR shall be determined by a series of creep rupture tests under constant pressure at the qualification test temperature. The procedure as described in ASTM D2992-12, Procedure B shall be used. No data points below 10 hours shall be included in regression calculations.

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.

5.3.3.4 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 nonpermissible failure mode is ejection of the pipe from the fitting or coupler.

5.3.4 Establishing Short-term Burst Characteristics

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 samples 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 J 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 samples 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.

5.3.5 Qualification of Product Variants

5.3.5.1 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.

5.3.5.2 Qualification of Product Variants Requiring a Two-sample Test

A minimum of two samples 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 at the qualification test temperature. Both samples shall not fail before 1000 hours. Retesting shall be in accordance with 5.8. 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 E.

5.3.6 Maximum Pressure Rating

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 F for guidance on other fluids);

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

d) installed in full compliance with manufacturer's recommendations and requirements (refer to Annex D for guidance on handling, installation and operation practices).

If operating conditions are outside these baseline conditions, additional testing or analysis shall be considered.

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 FSns are presented in Annex F.

5.4 Field End-fittings and Field Couplings

5.4.1 General

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.

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.

5.4.2 Qualification of Field-fittings for Product Family Representative

5.4.2.1 Field-fittings Used for Testing

If field-fittings are used for testing according to 5.2 or 5.3.3 they are considered to be qualified and testing in accordance with 5.4.3 is still required.

5.4.2.2 Laboratory Fittings Used for Testing

Where laboratory test fittings are used in 5.2 or 5.3.3, testing shall be performed in accordance with 5.2.5 or 5.3.5 using field-fittings to confirm that the field-fittings do not adversely affect the MPR. The only permissible mode of failure when qualifying the field-fittings shall be tensile rupture of the reinforcement and testing in accordance with 5.4.3 is still required.

5.4.3 Elevated Temperature Test

5.4.3.1 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. As a minimum, the variants selected shall be:

a) the smallest and largest diameters in each pressure rating group; or

b) the lowest and highest pressure in each size group.

Consideration should be given to the effect of dimensional tolerances at intermediate diameters

5.4.3.2 Elevated Temperature Test Procedure

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

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

where

α is the time-temperature shift factor

$t_{\text{Design Life}}$ is the design life time (hours)

t_{Test} ¡s the test time (hours)

log is log base 10

ΔT is the test temperature minus the product's MAOT.

For products with polyethylene materials in accordance with Table 1, the test duration shall be calculated using α= 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 test period shall be at least the time indicated in the formula above. 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 using this test. Retesting shall be in accordance with 5.8.

EXAMPLE 1 If $t_{\text{Design Life}}$ = 175,000 hours, α = 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 coupler type to be qualified at least two end-fittings or couplers shall be tested and the length of the spool piece between the two shall be as in 5.2.3.1 or 5.3.3.1 as applicable. All specimens shall survive without leakage for the full test period.

Following the elevated temperature test each test piece shall be depressurized and stored at ambient for at least 24 hours in air. The test pieces 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.

5.4.4 Temperature Cycling Test

The manufacturer shall specify the allowable temperature cycling range. The manufacturer shall also conduct tests on the highest pressure class of the product family using two samples of the smallest and two samples of the largest pipe diameter in the sequence described below:

a) condition the pipe specimen to the connector's lowest allowable installation temperature and maintain for a minimum of 2.5 hours;

NOTE At this temperature, install the fittings in accordance with the manufacturer's written instructions.

b) condition the specimen to the MAOT and maintain for a minimum of 2.5 hours;

c) condition the specimen to the specified lower test temperature (MAOT minus allowable temperature cycling range) and maintain for a minimum of 2.5 hours;

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

e) condition the sample at ambient temperature for 2.5 hours minimum; and

f) perform a pressure leak test of at least 1.5× the NPR for a minimum of two minutes at ambient conditions where there shall be no leakage in two minutes to pass this test.

For bonded pipe constructions, visual examination of the pipe following this test shall show no disbonding.

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

5.4.5 End-fitting and Coupling Requalification

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

5.5 Determination of Other Pipe System Characteristics

5.5.1 Rapid Decompression Testing of Pipe Structure for Gas or Multiphase Service

Rapid decompression testing shall be conducted at the highest nominal pressure rating and the maximum design temperature of the product family. Testing shall be performed in accordance with the laboratory test method outlined in Annex C to demonstrate that the design of pipe and fittings is such that there is no collapse, disbondment, blistering, or cover blow off.

5.5.2 Minimum Bend Radius/Respooling Test

5.5.2.1 Operating MBR

The operating MBR shall be specified by the manufacturer and confirmed by 1000-hour testing in accordance with 5.3.5.2 for nonmetallic reinforced pipe. For steel reinforced pipe, two test specimens shall be short-term burst pressure tested in accordance with 5.2.4 and each burst pressure shall be greater than or equal to MPR/F_d.

The manufacturer shall also conduct tests on the highest pressure class of the product family using two samples of the smallest and two samples of the largest pipe diameter.

The samples 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 5.8.

5.5.2.2 Handling MBR and Preconditioning

If the handling MBR is smaller than the operating MBR, precondition the samples to the handling MBR and perform the test in 5.5.2.1 at the operating MBR. If the handling MBR is equal to or greater than the operating MBR, test 5.5.2.1 satisfies this requirement. If unsuccessful, all samples shall be preconditioned to the handling MBR prior to performing PFR qualification testing to 5.2.3 for steel reinforced pipe or 5.3.3 for nonmetallic reinforced pipe.

5.5.2.3 Preconditioning at Operating MBR

The effect of handling and spooling on pipe performance shall be demonstrated by conditioning two samples with 10 bending cycles to the operating MBR and confirmed by means of a burst test in accordance with 5.2.4 for steel reinforced pipe or a 1000-hour test in accordance with 5.3.5.2 for nonmetallic reinforced pipe. Retesting shall be in accordance with 5.8.

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 samples for full qualification shall be conditioned with 10 bending cycles at the operating MBR.

5.5.2.4 Respooling Preconditioning

If respooling is allowed, precondition two samples 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 5.2.4 for steel reinforced pipe or a 1000-hour test in accordance with 5.3.5.2 for nonmetallic reinforced pipe. Retesting shall be in accordance with 5.8.

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 5.5.2.3 are satisfied by this test.

If this test (or the retest) is unsuccessful, all samples shall be preconditioned to the respooling MBR prior to performing PFR qualification testing to 5.2.3 for steel reinforced pipe or 5.3.3 for nonmetallic reinforced pipe.

5.5.3 Axial Load Capability

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 or couplings attached, the manufacturer shall conduct this test on the assembled pipe body with end-fittings or couplings.

Two samples 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 5.3.5.2 for nonmetallic reinforced pipe. For steel reinforced pipe, two test specimens shall be short-term burst pressure tested in accordance with 5.2.4 and each burst pressure shall be greater than or equal to MPR/F_d. Retesting shall be in accordance with 5.8.

The target axial tension load shall be achieved in no less than 1 minute and no more than 20 minutes.

5.5.4 External Load Performance

External load performance shall be characterized using ASTM D2412.

5.5.5 Minimum Allowable Operating Temperature Test

The manufacturer shall specify the minimum allowable operating temperature. The manufacturer shall also conduct tests on the highest pressure class of the product family using two samples of the smallest and two samples of the largest pipe diameter. Only field-fittings qualified by the pipe manufacturer shall be used:

a) condition the specimen until it reaches 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 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.

5.6 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 different suppliers that comply with the standards of Table 1 for PE and have the same ASTM or ISO material designation code will not constitute a change and will not require any additional testing. For other thermoplastic materials, the ASTM or ISO material designation code must fully describe the relevant properties of the qualified material. Material from a different supplier shall be consistent with the performance of the originally qualified material in accordance with the properties in Table 2. For thermoplastic materials where no industry accepted standard exists, changes to properties described in Table 2 shall require partial requalification as well as accelerated life testing of the end-connection system in accordance with 5.4.3.

Material changes in accordance with Table 3 shall be accompanied by a technical justification of the effect of the change, together with partial requalification according to Section 12 of ASTM D2992-12 for nonmetallic reinforced pipe, except that the distribution of average 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; and burst testing according to 5.2.5 for steel reinforced pipe. 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. If samples fail to pass this test the manufacturer can choose to retest in accordance with 5.8. If the retest samples fail to pass, the changes shall require full qualification according to 5.3.3 or 5.2.3.

Changes to the liner or cover as described in Table 3 shall also require accelerated life testing of the end-connection system in accordance with 5.4.3 as a minimum.

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 3 shall be subject to full qualification according to Section 5.

Table 3—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. A design change in thickness of liner or cover. Compounds not part of the PFR qualification process shall also be tested in accordance with 5.7, unless specifically exempt by the technical justification. All compounds shall be qualified in accordance with Section 4. Any Acceptable Change shall also be tested in accordance with 5.4.3, and, unless specifically exempt by the technical justification, with other tests from 5.4 and 5.5.
Reinforcement	Material supplier Supplier's grade and specification Filament diameter Tow size/configuration
Reinforcement Matrix and Adhesives	Material supplier Grade Thermoset curing system manufacturer Thermoset curing system grade Thermoset T_g
Manufacturing	Transfer of manufacture from one plant to another or additional manufacturing lines or locations. Transfer from prototype to equivalent commercial production manufacturing.

5.7 Other Required Testing

5.7.1 General

Certain product properties, described in this section, do not have specified requirements, but are nevertheless important in pipe system design and shall be provided by the manufacturer.

5.7.2 Solar Radiation Resistance

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.

5.7.3 Impact Resistance

The manufacturer shall quote the impact energy resistance of the pipe at minimum installation temperature. Two pipe samples 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 5.3.5.2 for nonmetallic reinforced pipe. For steel reinforced pipe, the two test specimens shall be short-term burst pressure tested in accordance with 5.2.4 and each burst pressure shall be greater than or equal to MPR/F_d. Retesting shall be in accordance with 5.8.

The manufacturer shall also conduct a two-sample test on the smallest and largest pipe diameter for the highest pressure class of each product family.

Following impact testing, the cover shall provide adequate protection to the reinforcement from the external environment.

5.7.4 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 sample shall be a minimum length of 6× the pipe diameter. 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. The manufacturer shall also conduct a two-sample test on the smallest and largest pipe diameter for the highest pressure class of each product family.

5.7.5 Growth and Shrinkage on Application of Pressure

The manufacturer shall measure and quote changes in pipe length and diameter which takes place as the pipe is pressurized from ambient pressure up to and including hydrotest pressure. The manufacturer shall also conduct a two-sample test on the smallest and largest pipe diameter for the highest pressure class of each product family.

5.8 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 are to 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.

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 sample be taken and have that sample 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 samples of pipe body 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 5.2.3.3, 5.2.5, or 5.3.4.

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 5.3.4.

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

NOTE The addition of the 90 % term for non-metallic pipe was established in recognition of the possibility that the initial samples used to create the lower prediction bound may have been randomly taken from product manufactured with reinforcement with an above average reinforcement strength. In comparison, the steel reinforced pipe uses a calculated strength based on specified minimum reinforcement strength values.

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 at the qualification test temperature.

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 samples 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 samples 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 batch shall be rejected but the manufacturer may elect to make retests on two additional replicate samples from the same batch. The batch shall be accepted if both of the retest samples conform to the requirements. The batch shall be rejected if either retest specimen fails to conform. If both fail, the batch shall be rejected.

6.4.3 Hydrostatic Test

The hydrostatic test pressure shall be a minimum of 1.3× the nominal pressure rating for steel reinforced pipe, or a minimum of 1.3× nominal pressure rating for non-metallic reinforced pipe, 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 held until stabilized. 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.

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 couplers. 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

NOTE 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 document the tolerances to be used for 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. As a minimum, tolerances shall be specified for the outside diameter and thickness of the liner, and the thickness of the structural layer.

7.2 Marking

7.2.1 Pipe Marking

7.2.1.1 General

The following information shall be printed on the OD:

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; and

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

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.

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 a qualification test report demonstrating conformance to this specification and it shall be made available for review on request.

8.5 Project Information Checklist

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

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 in Annex D.

Annex A
(informative)

API Monogram Program
Use of the API Monogram by Licensees

A.1 Scope

A.1.1 Applicability

This annex is normative (mandatory) for products supplied bearing the API Monogram and manufactured at a facility licensed by API; for all other instances it is not applicable.

A.1.2 General

The API Monogram® is a registered certification mark owned by the American Petroleum Institute (API) and authorized for licensing by the API Board of Directors. Through the API Monogram Program, API licenses product manufacturers to apply the API Monogram to products which comply with product specifications and have been manufactured under a quality management system that meets the requirements of API Q1. API maintains a complete, searchable list of all Monogram licensees on the API Composite List website (www.api.org/compositelist).

The application of the API Monogram and license number on products constitutes a representation and warranty by the licensee to API and to purchasers of the products that, as of the date indicated, the products were manufactured under a quality management system conforming to the requirements of API Q1 and that the product conforms in every detail with the applicable standard(s) or product specification(s). API Monogram program licenses are issued only after an on-site audit has verified that an organization has implemented and continually maintained a quality management system that meets the requirements of API Q1 and that the resulting products satisfy the requirements of the applicable API product specification(s) and/or standard(s). Although any manufacturer may claim that its products meet API product requirements without monogramming them, only manufacturers with a license from API can apply the API Monogram to their products.

Together with the requirements of the API Monogram license agreement, this annex establishes the requirements for those organizations who wish to voluntarily obtain an API license to provide API monogrammed products that satisfy the requirements of the applicable API product specification(s) and/or standard(s) and API Monogram Program requirements.

For information on becoming an API Monogram Licensee, please contact API, Certification Programs, 1220 L Street NW, Washington, DC 20005 or call (202) 682-8145 or by email at certification@api.org.

A.2 Normative References

In addition to the referenced standards listed earlier in this document, this annex references the following standard:

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

For Licensees under the Monogram Program, the latest version of this document shall be used. The requirements identified therein are mandatory.

A.3 API Monogram Program: Licensee Responsibilities

A.3.1 Monogram Program Requirements

For all organizations desiring to acquire and maintain a license to use the API Monogram, conformance with the following shall be required at all times:

a) quality management system requirements of API Q1;

b) API Monogram Program requirements of API Q1, Annex A;

c) requirements contained in the API product specification(s) to which the organization is licensed; and

d) requirements contained in the API Monogram Program License Agreement.

A.3.2 Control of the Application and Removal of the API Monogram

Each licensee shall control the application and removal of the API Monogram in accordance with the following:

a) products that do not conform to API specified requirements shall not bear the API Monogram;

b) each licensee shall develop and maintain an API Monogram marking procedure that documents the marking/ monogramming requirements specified by this annex and any applicable API product specification(s) and/or standard(s). The marking procedure shall:

   1) define the authority responsible for application and removal of the API Monogram and license number;

   2) define the method(s) used to apply the Monogram and license number;

   3) identify the location on the product where the API Monogram and license number are to be applied;

   4) require the application of the date of manufacture of the product in conjunction with the use of the API Monogram and license number;

   5) require that the date of manufacture, at a minimum, be two digits representing the month and two digits representing the year (e.g. 05-12 for May 2012) unless otherwise stipulated in the applicable API product specification(s) or standard(s); and

   6) define the application of all other required API product specification(s) and/or standard(s) marking requirements.

c) only an API licensee shall apply the API Monogram and its designated license number to API monogrammable products;

d) the API Monogram and license number, when issued, are site-specific and subsequently the API Monogram shall only be applied at that site specific licensed facility location; and

e) the API Monogram may be applied at any time appropriate during the production process but shall be removed in accordance with the licensee's API Monogram marking procedure if the product is subsequently found to be out of conformance with any of the requirements of the applicable API product specification(s) and/or standard(s) and API Monogram Program.

For certain manufacturing processes or types of products, alternative API Monogram marking procedures may be acceptable. Requirements for alternative API Monogram marking are detailed in the, API Monogram Program

Alternative Marking of Products License Agreement, available on the API Monogram Program website at http://www.api.org/alternative-marking.

A.3.3 Design and Design Documentation

Each licensee and/or applicant for licensing shall maintain current design documentation as identified in API Q1 for all of the applicable products that fall under the scope of each Monogram license. The design document information shall provide objective evidence that the product design meets the requirements of the applicable and most current API product specification(s) and/or standard(s). The design documentation shall be made available during API audits of the facility.

In specific instances, the exclusion of design activities is allowed under the Monogram Program, as detailed in Advisory #6, available on API Monogram Program website at http://www.api.org/advisories.

A.3.4 Manufacturing Capability

The API Monogram Program is designed to identify facilities that have demonstrated the ability to manufacture equipment that conforms to API specifications and/or standards. API may refuse initial licensing or suspend current licensing based on a facility's level of manufacturing capability. If API determines that an additional review is warranted, API may perform additional audits (at the organization's expense) of any subcontractors to ensure their conformance with the requirements of the applicable API product specification(s) and/or standard(s).

A.3.5 Use of the API Monogram in Advertising

An API Monogram licensee shall not use the API Monogram and/or license number on letterheads, buildings or other structures, websites or in any advertising without an express statement of fact describing the scope of Licensee's authorization (license number and product specification). The Licensee should contact API for guidance on the use of the API Monogram other than on products.

A.4 Product Marking Requirements

A.4.1 General

These marking requirements shall apply only to those API Licensees wishing to mark applicable products in conjunction with the requirements of the API Monogram Program.

A.4.2 Product Specification Identification

Manufacturers shall mark products as specified by the applicable API specifications or standards. Marking shall include reference to the applicable API specification and/or standard. Unless otherwise specified, reference to the API specifications and/or standards shall be, as a minimum, “API [Document Number]” (e.g. API 6A or API 600). Unless otherwise specified, when space allows, the marking may include use of “Spec” or “Std”, as applicable (e.g. API Spec 6A or API Std 600).

A.4.3 Units

Products shall be marked with units as specified in the API specification and/or standard. If not specified, equipment shall be marked with U.S. customary (USC) units. Use of dual units [USC units and metric (SI) units] may be acceptable, if such units are allowed by the applicable product specification and/or standard.

A.4.4 Nameplates

Nameplates, when applicable, shall be made of a corrosion-resistant material unless otherwise specified by the API specification and/or standard. Nameplate shall be located as specified by the API specification and/or standard. If the location is not specified, then the licensee shall develop and maintain a procedure detailing the location to which the nameplate shall be applied. Nameplates may be attached at any time during the manufacturing process.

The API Monogram and license number shall be marked on the nameplate, in addition to the other product marking requirements specified by the applicable product specification and/or standard.

A.4.5 License Number

The API Monogram license number shall not be used unless it is marked in conjunction with the API Monogram. The license number shall be used in close proximity to the API Monogram.

A.5 API Monogram Program: Nonconformance Reporting

API solicits information on products that are found to be nonconforming with API specified requirements, as well as field failures (or malfunctions), which are judged to be caused by either specification and/or standard deficiencies or nonconformities against API specified requirements. Customers are requested to report to API all problems with API monogrammed products. A nonconformance may be reported using the API Nonconformance Reporting System available at http://compositelist.api.org/ncr.aspx.

Annex B
(informative)

Project Application Information

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

Basic Design Data	
Nominal Pipe, 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	
CO2/H2S 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	
Corrosion Protection Requirements (CP, etc., including end-fittings/ couplings outer material)	
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 C
(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. Through a combination of analysis and testing the manufacturer shall demonstrate that liner collapse, multilayer disbondment, or cover rupture shall not occur. Testing shall be by the following method.

C.1 Pipe Specimen Preparation

C.1.1 At least one sample shall be tested and shall be traceable to a production run, which shall have passed all QA requirements;

C.1.2 Each specimen shall be uniquely identified with a laboratory specimen number, traceable to the production run; and

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

C.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.

C.2.1 Attach end-fittings to the specimen according to standard assembly practices;

C.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 $\times$ 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.

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

C.2.4 Upon completion of the hold period, rapidly remove pressure from the specimen. Rate of depressurization shall not be less than 100 psi (6.9 bar) per minute;

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

Annex D
(informative)

Handling, Storage, Installation, and Operation

D.1 General

Warning—Guidelines are recommended to take account of the potential danger of the stored energy of the pipe when wound on a spool and dimensional impacts storage may induce.

This Annex is intended to provide guidance for products but is not intended to cover all scenarios and situations. The manufacturer should provide guidance as applicable for the specific product that is being installed.

Spoolable reinforced plastic line pipe may be stored, handled and deployed using spools or coils. This demands installation techniques that may differ substantially from methods used to install jointed steel or fiberglass pipe.

Each manufacturer should develop and publish guidelines, procedures, installation check lists, and precautions, as appropriate which cover activities from receipt of the pipe until post construction activities are completed. Specific attention should be paid to items that are product specific or are not governed by other regulatory requirements.

In general, these guidelines should minimize the opportunity for external damage to the pipe through contact with lifting gear and installation equipment and practices, and ensure that pipe stays within its performance capability, e.g. bend radius, installation methods and backfill precautions.

D.2 Post-delivery Storage and Handling

D.2.1 Visual inspection of all pipes at time of delivery and as transported should be undertaken by competent personnel as soon as it reaches the site. Any damage should be marked for assessment and repair before installation. Similar visual inspection should be applied throughout the installation and commissioning process where practicable.

D.2.2 The manufacturer should provide guidelines for acceptable storage of pipe materials, including any limitations for cumulative outdoor, unprotected storage time frames. The manufacturer should stipulate whether reels should be stored upright or laid on side and if the orientation could result in detrimental effects if stored in an undesirable position for extended periods. The manufacturer should include information for pipe provided in coil form (without the support of structural reels) and the appropriate storage and handling methods, including the maximum allowable number of coils that may be stacked.

D.2.3 The manufacturer should include in published guidelines, all safety precautions, dimensions per length, weights of pipe, weights of spools including tare weights or methods to obtain such, and recommendations for unique safe handling techniques that should be employed. The procedures should provide guidance for handling pipe in a safe manner to control stored energy and any specific procedures for handling in temperatures that warrant additional precautions or measures, such as extremely cold or hot environments.

D.2.4 Consideration of hazards during transportation should include product weights, height, rollover, chocking, securing, etc.

D.3 Unspooling

D.3.1 For most products, a spooling frame suitable for supporting and controlling the spool is utilized, typically with hydraulic drive and integral brake, and the capability to lift the spool off the ground and provide a secure mounting. When applicable, the manufacturer should provide information regarding essential variables, such as maximum pulling load allowed and recommended braking procedures, to enable the installer to select the appropriate

equipment to use in the unspooling process. Experience has shown that pipe can be unspooled in a number of ways. The two most common are discussed below.

D.3.1.1 *Unspooling from a Stationary Spool*—If the spooling frame is stationary, pipe can be deployed by pulling the pipe off the spool. This method is useful where soil is not excessively rocky or abrasive. Experience has shown that line pipe may be pulled by a pickup truck, tractor, backhoe, or similar vehicle. The maximum pulling load, as measured by a load cell inserted between the pipe and the pulling equipment, should not exceed the maximum allowable axial load of the pipe being deployed and should be recorded and retained as part of the installation documentation. Tension should be maintained on the pipe at the spool at all times to prevent "bird nesting" of several layers of spooled pipe. Pipe should not be cut until the ends are securely restrained due to the residual "elastic" energy in the spooled pipe.

D.3.1.2 *Unspooling from a Moving Spool*—Pipe can also be unspooled by anchoring the free-end of the pipe at the starting point and pulling the spool away from that point on a trailer or truck bed along the right-of-way. This is the preferred method for areas with rocky or very abrasive soil and for lines that are not straight. The center-of-gravity of the vehicle with the spool on board should all be evaluated to prevent overturning along the intended route.

D.3.2 Each manufacturer should specify when, if ever, use of rerounding techniques is necessary and should be employed. The manufacturer should provide to the installer procedures detailing the types of acceptable equipment for rerounding the pipe and acceptable range of tolerances for rerounding pressures and straightening pressures.

D.3.3 Whichever method is used for unspooling, visual examination of the cover should be performed to ensure no nonsuperficial damage occurs during the unspooling process. If rerounding equipment is used, visual examination should be conducted by the installer and repairs made as required.

D.4 Joining Equipment and Procedures

D.4.1 The manufacturer's procedures and guidelines should contain details on how to identify the product, including connectors, using factory applied markings. Each manufacturer should identify tools and equipment required for proper installation and describes maintenance procedures for any specialized equipment used to join pipe materials.

D.4.2 The manufacturer should provide detailed procedures, either by inclusion of or reference to separate documentation, that have been proven to produce fluid tight joints when properly executed. The procedures should be available to persons making and inspecting joints. Procedures should identify acceptable parameters such as temperature limitations when joining process may be performed, acceptable tolerances for pipe ovality, and methods for determining acceptability of the final joint makeup. Guidelines should provide the installer or inspector with suggested methodologies for documenting key process steps necessary to produce acceptable joints such as recording torque values, fusion temperatures, and insertion depth of fitting onto host pipe.

Maintenance of specialized equipment should detail maintenance requirements, maintenance intervals, and acceptable tolerances for parts subject to wear that if not maintained properly could have an adverse effect on producing sound joints.

D.4.3 The process steps used to prepare and install fluid tight joints discussed above should be in sufficient detail to substantiate, if requested, the process used for qualification and documentation of an individual's knowledge, skills, and ability to perform joining.

D.5 Installations

D.5.1 Buried Installations

D.5.1.1 Line pipe can be buried either by conventional “trench and backfill” methods using conventional trenching equipment, directional drilling, or “plowing in” with specialized trenching plows.

D.5.1.2 For buried installations, consideration should be given to the method of attachment to surface equipment at each pipe end. This is particularly critical in areas subject to soil movement or heave. The manufacturer should provide minimum acceptance criteria for slope and support within the installation procedures. The published material should specify recommendations for bedding and backfill material, including maximum rock size allowed, if any, and compaction techniques that will protect the piping material from damage. Procedures should establish acceptable parameters for any changes of direction taking into consideration the operating MBR of the product. The burial procedures should specify any additional requirements necessary to minimize localized stresses to the pipe and fittings. If external appurtenances are used to facilitate locating practices, the guidelines for tracer wire and/or warning tape in buried or submerged applications should include the manufacturer's recommendations for separation distance for appurtenances if applicable.

D.5.1.3 Guidelines for cotrenching with other pipelines or other underground infrastructure should be included and made available if the project owner does not have standards or if pipe material considerations warrant exceedance of the project owner's specifications. The manufacturer should define an adequate separation distance to address potential damage from heat sources and provide adequate clearances to allow for future maintenance or repairs should it become necessary. Distances should provide adequate room for specialized tools without inducing damage to target pipe or adjacent facilities.

D.5.1.4 The manufacturer should provide guidance for directional drilling including maximum axial pull load, managing crossings, and visual inspection of the pipe after the pulling is complete to ensure pipeline serviceability. A sufficient amount of pipe should be pulled past the bore exit hole to allow for a 360° visual evaluation of the pipe as well as to allow for pipe relaxation.

D.5.1.5 Procedures published by the manufacturer should define design limits for external load forces and include recommendations to adequately withstand the dynamic forces exerted by anticipated traffic and environmentally induced loads.

D.5.1.6 If applicable, the manufacturer should provide recommendations for attaching cathodic protection associated appurtenances to the pipeline in a manner that induces no adverse stress concentrators on the pipe. Applicable procedures for installing and applying any field applied protective coating materials should be included.

D.5.1.7 The manufacturer should provide recommendations for how to manage end loads which may be developed during installation or operation that may lead to premature failure of the pipe.

D.5.2 Surface Installations

D.5.2.1 During the design phase, the designer should evaluate pressure and thermal expansion or contraction, and anticipated temperature swings (including black-body absorption of the line pipe), although expansion loops are generally not necessary. The manufacturer should provide sufficient detail regarding expansion coefficients for the designer to adequately compensate for the effects based upon the intended installation environment.

D.5.2.2 The manufacturer should specify any requirements for restraining the pipe on surface to prevent movement of the pipe that may lead to damage. The manufacturer should provide recommendations for types of and acceptable distance of spans between supports, including any recommendations for support to pipe interface materials. Designs for supports should be installed in a manner to minimize localized stresses. Bends in the pipe should always be made with a radius greater than the operating MBR of the product.

D.5.3 Relining Applications

D.5.3.1 Relining is a technique used to rehabilitate lines by pulling or inserting pipe into the existing host line.

D.5.3.2 In relining applications there should be adequate clearance between the outside diameter of the reinforced plastic line pipe and the inside diameter of the existing steel line. Consideration should be given to obstructions in the steel pipeline, e.g. any unexpected sharp turns, dents or kinks in the pipe, or internal weld material. Such defects can

reduce the effective ID of the steel line and damage the plastic line pipe. Procedures and guidelines published by the manufacturer should specify acceptable “damage” allowance of the cover material.

D.5.3.3 If wire rope is used as the pull line a swivel should be installed between the pull line and line pipe to prevent the wire rope from applying torque to the pipe as it is pulled during installation. A pulling load indicator system which provides real-time read out of axial pull during installation is typically utilized. Actual pulling force should be limited to the product's published maximum allowable axial load and should be recorded and retained as part of the installation documentation.

D.5.3.4 The manufacturer should provide guidance regarding the use of fittings that may reside within a host pipe as part of a relining project.

D.5.3.5 Upon exit at the termination end of the pull a sufficient amount of pipe should be pulled past the host pipe to allow for a 360° evaluation of the pipe to ensure the pull through the host has not caused any damage that will affect the serviceability of the new pipeline as well as to allow for pipe relaxation. The pipe at the end of the host pipe should be suitably restrained to prevent gross movement at the ends, which may be induced by pressure- or temperature-induced expansion that cannot be accommodated by “snaking” along the entire length of pipe inside the host pipe.

D.5.4 Other Installations

The manufacturer should provide guidance for installing pipe for other applications including shallow water, wet lands, swamps, muskeg, etc. as applicable.

D.6 Field Testing

D.6.1 Hydrostatic testing of field installed line pipe should be undertaken to verify the integrity of installed end-fittings and connectors. Suitable safety precautions should be taken throughout, bearing in mind that the stored energy of pipe can be large. Pneumatic pressure testing may be preferred in certain circumstances, in which case additional safety precautions are warranted.

D.6.2 Each manufacturer should provide guidelines for pressure testing. There should be specific guidance for testing complex systems in sections, for having adequate restraint during testing, and for dealing with the effect of elevation changes on the applied test pressure.

D.6.3 The customer and applicable regulations should define the minimum test pressure and duration. The maximum allowable test pressure to be applied during testing should be provided. This maximum allowable test pressure should generally be greater than the minimum required test pressure to allow for stabilization effects (relaxation and temperature) as well as effects of elevation changes along the pipe.

D.7 Repair Procedures

The procedures should include steps to evaluate the need for and, if necessary, how to facilitate repairs to the pipeline. In addition, procedures for repairing in-service pipelines should be provided to the operator.

D.8 Operations

The manufacturer should provide operations guidance that will include the following:

a) chemical compatibility;

b) annulus pressure buildup management;

c) rapid 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) possible accumulation and associated hazard of permeated gases in the pipe wall, at a vent hole, in the annulus, etc.;

i) other information as applicable or agreed between the manufacturer and purchaser or end-user.

D.9 Decommissioning and Abandonment

Pipeline decommissioning and abandonment should be in accordance with local regulations.

Annex E
(informative)

Test Pressure Scaling 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 LPL 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:

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

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 given as follows:

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

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 as follows:

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

where

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

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

where

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

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

where

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

Annex F
(informative)

Service Factors

It is the responsibility of the pipeline system design engineer to 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 F_{Sn}s as shown below:

$$MOP = NPR \times F_{S0} \times F_{S1} \times \ldots F_{Sn} \quad \text{(F.1)}$$

Service factors (FS) 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 and not fluid compatibility.

Guidelines for fluid, FS (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 and multiphase services; and

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

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 G
(normative)

Requirements for Cyclic Pressure Fluctuations

G.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.

G.2 Cyclic Loading Definition

Cyclic loading is defined as the following:

a) More than 7000 cycles; and

b) $\Delta P/NPR \geq 6$ %.

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

G.3 Test Method

Cyclic regression analysis 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 an appropriate calculation methodology.

G.3.1 Cyclic Regression Curve Test Method on Reinforcement Material Samples

Fatigue curves for reinforcement material samples shall be created using a suitable test method and analyzed according to ASTM E739, D2992-12, or equivalent. In addition, testing according to G.3.2 of at least two pipes with field-fittings shall be completed and shown to be conservatively represented by the reinforcement material test results. This can be shown by testing two pipe samples to the 7000 cycle LPL intercept. Both samples shall not fail before the 7000 cycle LPL 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 3 shall be accompanied by a technical justification of the effect of the change, together with partial requalification according to Section 12 of ASTM D2992-12, 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.

G.3.2 Cyclic Regression Curve Test Method on Pipe Samples

Regression analysis for the PFR requires a minimum of 18 points carried out at the MAOT and in accordance with ASTM D2992-12, 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 D2992-12 are not applicable;

b) the cycle frequency may be less than 25 cycles/minute for pipe samples and greater than 25 cycles/minute for reinforcement material samples;

c) the 15 million cycle sample 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 3 shall be accompanied by a technical justification of the effect of the change, together with partial requalification according to Section 12 of ASTM D2992-12, 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) those specimens that have not failed after more than 1 million cycles may be included as failures in establishing the regression line.

G.3.3 Service Factor Confirmation

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).

To confirm there is no degradation in pipe strength due to the allowable number of cycles, precondition at least two pipe specimens with field-fittings to the allowable number of cycles at the MAOT and successfully pass a short-term burst pressure test in accordance with 5.2.4 for steel reinforced pipe, or pass a 1000-hour constant pressure test according to 5.3.5.2 for non-metallic reinforced pipe. Retesting shall be in accordance with 5.8. This proof is only required at one pressure which shall be taken between 10,000 and 1 million cycles along the established regression curve and would not be required for all applications once established.

Annex H
(informative)

Regression Curve Terminology

Using the analysis method of ASTM D2992-12 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 H.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 H.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. 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 LCLRCRT at temperatures between two regression curves shall be based on the following equation:

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

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.

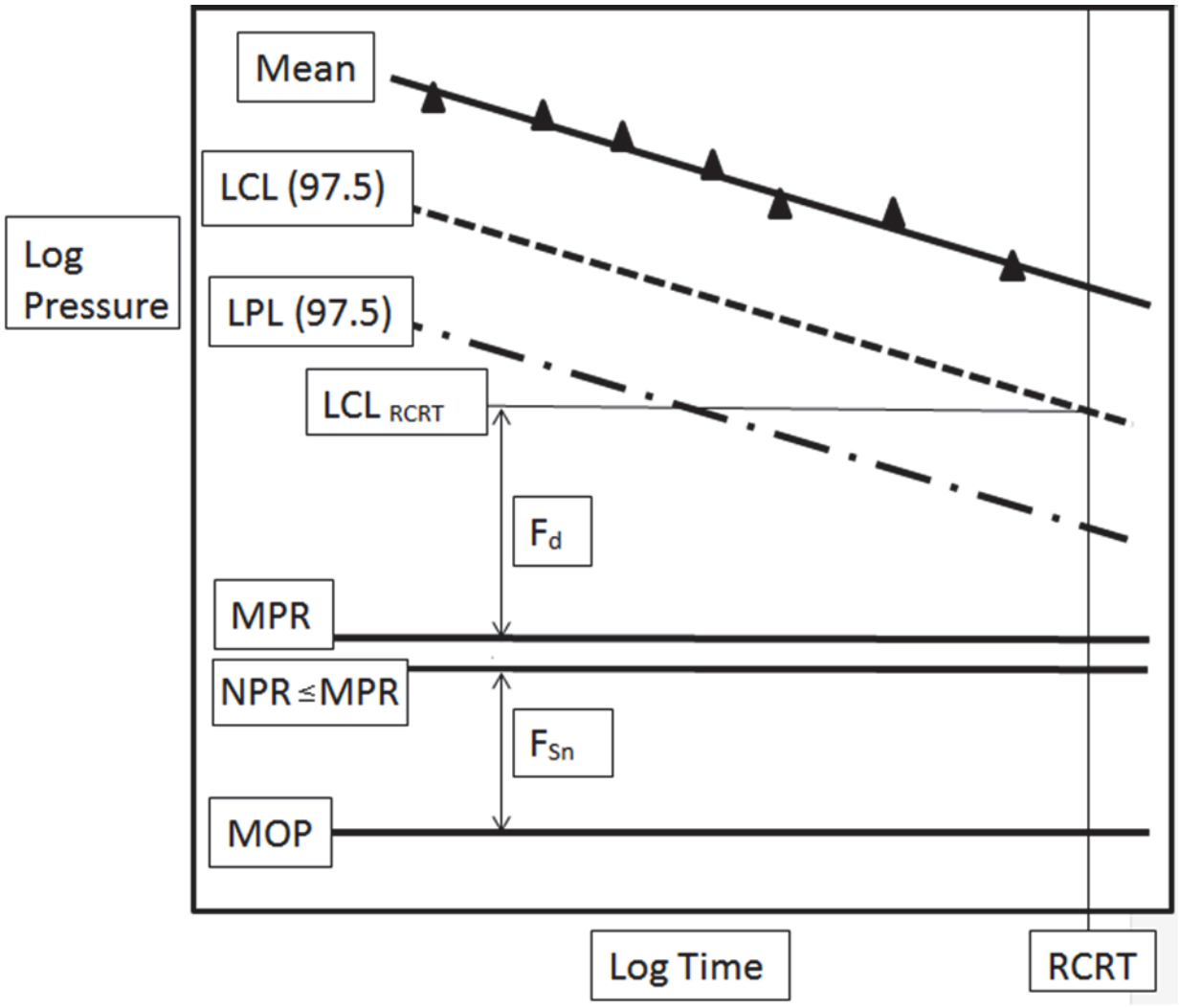

Figure H.1—Regression Curve, LCL Curve, LPL Curve, and Use of the LCL_{RCRT} to Define MPR and MOP

Annex I
(informative)

Product Literature

The manufacturer should, as a minimum, provide the purchaser with product literature for each pipe structure including the following:

a) dimensions that include:

   1) inside diameter,

   2) outside diameter,

   3) minimum reinforced pipe wall thickness,

   4) pipe weight per unit length (empty and filled with water),

   5) maximum end-fitting outside diameter,

   6) description of materials used in each layer of the product,

b) minimum and maximum operating temperatures,

c) maximum pressure rating and maximum operating pressure for different fluids,

d) maximum allowable external pressure difference,

e) minimum bend radius for storage and operation,

f) thermal expansion coefficient,

g) axial growth or shrinkage with application of internal pressure (up to 1.5× nominal pressure rating),

h) cyclic pressure operating guidance,

i) maximum allowable tensile load in accordance with 5.5.3.

Annex J
(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:

$$\text{Lower prediction bound} = \bar{x} - s\left[t_{(1-\infty,n-1)}\sqrt{1+\frac{1}{n}}\right] \quad \text{(J.1)}$$

where

n = number of previously tested data points

x_i = previously obtained test data values (i=1,n)

s = sample standard deviation = $\left(\dfrac{\sum_{i=1}^{n}(x_i-\bar{x})^2}{n-1}\right)^{1/2}$

$\bar{x}$ = average of the previously obtained test data values

$t_{(1-\alpha,n-1)}$ = the 100(1−α) 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 J.1. The value from the table shall be used when performing the calculation in accordance with Equation J.1.

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

Table J.1—Tabulation of $[t_{(1-\infty,n-1)}\sqrt{1+\frac{1}{n}}]$ for various values of n with α = 0.025

n	$[t_{(1-\infty,n-1)}\sqrt{1+\frac{1}{n}}]$	n	$[t_{(1-\infty,n-1)}\sqrt{1+\frac{1}{n}}]$	n	$[t_{(1-\infty,n-1)}\sqrt{1+\frac{1}{n}}]$
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

Table J.1—Tabulation of [$t_{(1-\infty,n-1)}\sqrt{1+\frac{1}{n}}$] for various values of n with α = 0.025

n	[$t_{(1-\infty,n-1)}\sqrt{1+\frac{1}{n}}$]	n	[$t_{(1-\infty,n-1)}\sqrt{1+\frac{1}{n}}$]	n	[$t_{(1-\infty,n-1)}\sqrt{1+\frac{1}{n}}$]
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

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