Designation: F3288/F3288M – 20

An American National Standard

Standard Specification for MRS-Rated Metric- and Inch-sized Crosslinked Polyethylene (PEX) Pressure Pipe[1]

This standard is issued under the fixed designation F3288/F3288M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers crosslinked polyethylene (PEX) pipe that is outside diameter controlled in metric pipe sizes (DN 16 to 1000) and inch pipe sizes (NPS 3 to 54), and pressure rated (see Appendix X1) using the MRS rating system. This Specification is intended for PEX pipe made by various processes, as long as the PEX pipe made by that process meets all the requirements of this Specification. Included are requirements and test methods for material, workmanship, UV protection, dimensions, hydrostatic sustained pressure, environmental stress cracking, stabilizer functionality, bent-pipe hydrostatic pressure, oxidative stability in potable chlorinated water, minimum operating temperature, degree of crosslinking, and hydrostatic burst pressure. Requirements for pipe markings are also given. The pipe covered by this specification is intended for pressure piping applications such as, industrial and general-purpose pipelines, potable water pipelines, fire – extinguishing pipelines, oil and gas producing applications to convey fluids such as oil, dry or wet gas, gas gathering, multiphase fluids, and non-potable oilfield water, and chemical pipelines. It is not intended for municipal natural gas distribution.

1.2 This specification also includes requirements for qualifying joints made using polyethylene electrofusion fittings and PEX pipe. Installation considerations are in X3.2.

NOTE 1—NPS fittings should not be used for DN sized pipe, and DN sized fittings should not be used for NPS pipe.

1.3 The text of this specification references notes, footnotes, and appendixes, which provide explanatory material. These notes and footnotes (excluding those in tables and figures) should not be considered as requirements of the specification.

1.4 *Units*—The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system are not necessarily exact equivalents; therefore, to ensure conformance with the standard, each system shall be used independently of the other, and values from the two systems shall not be combined.

1.4.1 For consistency with ISO 9080, MRS values are only in MPa and degrees Centigrade for conversion to the pipe material designation code (for example PEX pipe with an MRS of 8 MPa is called a PEX 80.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D618 Practice for Conditioning Plastics for Testing

D792 Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement

D1505 Test Method for Density of Plastics by the Density-Gradient Technique

D1598 Test Method for Time-to-Failure of Plastic Pipe Under Constant Internal Pressure

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

D1600 Terminology for Abbreviated Terms Relating to Plastics

D1603 Test Method for Carbon Black Content in Olefin Plastics

D2122 Test Method for Determining Dimensions of Thermoplastic Pipe and Fittings

D2290 Test Method for Apparent Hoop Tensile Strength of Plastic or Reinforced Plastic Pipe

[1] This specification is under the jurisdiction of ASTM Committee F17 on Plastic Piping Systems and is the direct responsibility of Subcommittee F17.26 on Olefin Based Pipe.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

D2565 Practice for Xenon-Arc Exposure of Plastics Intended for Outdoor Applications
D2765 Test Methods for Determination of Gel Content and Swell Ratio of Crosslinked Ethylene Plastics
D4218 Test Method for Determination of Carbon Black Content in Polyethylene Compounds by the Muffle-Furnace Technique
D5596 Test Method for Microscopic Evaluation of the Dispersion of Carbon Black in Polyolefin Geosynthetics
F412 Terminology Relating to Plastic Piping Systems
F2023 Test Method for Evaluating the Oxidative Resistance of Crosslinked Polyethylene (PEX) Pipe, Tubing and Systems to Hot Chlorinated Water
F2657 Test Method for Outdoor Weathering Exposure of Crosslinked Polyethylene (PEX) Tubing
F3203 Test Method for Determination of Gel Content of Crosslinked Polyethylene (PEX) Pipes and Tubing
F3373 Specification for Polyethylene (PE) Electrofusion Fittings for Outside Diameter Controlled Crosslinked Polyethylene (PEX) Pipe

2.2 *Federal Standard:*[3]
FED-STD-123 Marking for Shipment (Civil Agencies)

2.3 *Military Standard:*[3]
MIL-STD-129 Marking for Shipment and Storage

2.4 *NSF Standards:*[4]
NSF/ANSI 14 for Plastic Piping Components and Related Materials
NSF/ANSI 61 for Drinking Water System Components-Health Effects

2.5 *ISO Standards:*[5]
ISO 1167 Thermoplastics pipes, fittings and assemblies for the conveyance of fluids — Determination of the resistance to internal pressure — Part 1: General method
ISO 3126 Plastics piping systems – Plastics components – Determination of dimensions
ISO 9080 Plastics piping and ducting systems—Determination of the long-term hydrostatic strength of thermoplastics materials in pipe form by extrapolation
ISO 12162 Thermoplastics materials for pipes and fittings for pressure applications—Classification and designation— Overall service (design) coefficient
ISO 13477 Thermoplastics pipes for the conveyance of fluids — Determination of resistance to rapid crack propagation (RCP) — Small-scale steady-state test (S4 test)
ISO 13760 Plastics pipes for the conveyance of fluids under pressure — Miner's rule ~ Calculation method for cumulative damage
ISO 14531-1 Plastics pipes and fittings — Crosslinked polyethylene (PEX) pipe systems for the conveyance of gaseous fuels — Metric series — Specifications — Part 1: Pipes
ISO 18553 Method for the assessment of the degree of pigment or carbon black dispersion in polyolefin pipes, fittings and compounds.

2.6 *PPI Standards:*[6]
PPI TN-17 Crosslinked Polyethylene (PEX) Tubing
PPI TR-3 HDB/HDS/PDB/SDB/MRS/CRS Policies - Policies and Procedures for Developing Hydrostatic Design Basis (HDB), Hydrostatic Design Stresses (HDS), Pressure Design Basis (PDB), Strength Design Basis (SDB), Minimum Required Strength (MRS), and Categorized Required Strength (CRS) Ratings for Thermoplastic Piping Materials or Pipe
PPI TR-4 HDB/HDS/SDB/PDB/MRS/CRS Listed Materials, PPI Listing of Hydrostatic Design Basis (HDB), Hydrostatic Design Stress (HDS), Strength Design Basis (SDB), Pressure Design Basis (PDB), Minimum Required Strength (MRS), Categorized Required Strength (CRS) Ratings for Thermoplastic Piping Materials or Pipe

3. Terminology

3.1 *Definitions*—Unless otherwise specified, definitions, abbreviations and initials are in accordance with Terminology F412 and Terminology D1600.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *minimum required strength (MRS)*—see ISO 12162 for MRS definition.

3.2.1.1 *Discussion*—MRS is determined only at 20 °C and 50 years. For a design temperature other than 20 °C or a design time other than 50 years, CRS is used in place of MRS, as discussed in 3.2.2.

3.2.2 *categorized required strength (CRS) or CRS(θ,t), n*—see ISO 12162 for CRS definition.

3.2.2.1 *Discussion*—The MRS of a compound is determined before a CRS can be determined. CRS is used for a design time other than 50 years or a design temperature other than 20 °C. An example of the use of CRS is provided in Appendix X2.

3.2.3 *nominal diameter, DN, adj*— a designation for SI unit outside diameter controlled pipe sizes.

3.2.4 *nominal pipe size, NPS, adj*—a designation for inch-pound unit outside diameter controlled pipe sizes.

3.2.5 *overall design coefficient (C), n*—a factor with a value greater than 1, which takes into consideration material properties (C_M) and application service conditions (C_A), as well as properties of the components of a piping system other than those represented in the lower predictive limit. Minimum overall design coefficients (C_{min}) are specified in ISO 12162 for various plastic piping materials. For PEX, C_{min} is 1.25 as specified in ISO 12162. See Appendix X1 for further discussion on design coefficients.

[3] Available from DLA Document Services, Building 4/D, 700 Robbins Ave., Philadelphia, PA 19111-5094, http://quicksearch.dla.mil.
[4] Available from NSF International, P.O. Box 130140, 789 N. Dixboro Rd., Ann Arbor, MI 48105, http://www.nsf.org.
[5] Available from International Organization for Standardization (ISO), ISO Central Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, http://www.iso.org.
[6] Available from Plastics Pipe Institute (PPI), 105 Decker Court, Suite 825, Irving, TX 75062, http://www.plasticpipe.org.

$$C = C_M \times C_A = 1.25 \times C_A \text{ or} \quad (1)$$

$$C = 1.25 \times C_{A1} \times C_{A2} \times$$

...if there are multiple applications design coefficients

Discussion—design coefficients are sometimes referred to as reduction factors.

3.2.5.1 *material design coefficient (C_M), n*—factor that takes into account the properties of the plastic material. For PEX, the material coefficient (C_M) is 1.25, as specified in ISO 12162.

3.2.5.2 *application design coefficient (C_A), n*—a factor that takes into account various aspects of the installation or the application that the plastic pipe is used for. The application coefficient is left to the design engineer to incorporate via appropriate design codes and national regulations and should be dependent on the location of the pipeline, on the temperature, on the type of fluid being conveyed, and on the installation method.

3.2.6 *design stress (σ_S), n*—stress equal to the MRS or CRS divided by the overall design coefficient (C).

$$\sigma_S = (\text{MRS or CRS})/C \quad (2)$$

3.2.7 *maximum operating pressure (MOP), n*—the estimated maximum pressure the pipe is capable of withstanding continuously with a high degree of certainty that failure of the pipe will not occur, as shown in the following equations that are used in this specification to relate dimensions, design stress, and maximum operating pressure.

$$MOP = 2\sigma_S / [(D_o / t) - 1], \text{ or} \quad (3)$$

$$MOP = 2\sigma_S / (R\text{-}1)$$

For MOP at a temperature other than 20 °C or a time other than 50 years:

$$MOP = 2(CRS) / [(R\text{-}1)(C)], \quad (4)$$

$$MOP = 2(CRS) / [(R\text{-}1)(C_M \times C_A)] \quad (5)$$

where:

σ_S = design stress, MPa
MOP = maximum operating pressure, MPa
D_o = average outside diameter, see Table 1(mm) or Table 2 (in.)
t = minimum wall thickness, see Table 3 (mm) or Table 4 (in.)
R = standard dimension ratio (SDR) or dimension ratio (DR)
MRS = Minimum Required Strength, MPa
CRS = Categorized Required Strength, MPa
C = Overall Design Coefficient

3.2.7.1 *Discussion*—MOP is sometimes referred to as PN or nominal pressure

3.2.8 *material designation, n*—As used in this standard, the material designation for PEX pipe shall consist of the abbreviation for the type of plastic (PEX) followed by two or three Arabic digits, which are the MRS (in MPa only) times ten, as shown in Table 5.

TABLE 1 Outside Diameters and Tolerances for DN size PEX Pipe

DN Size	Minimum outside diameter (mm)	Maximum outside diameter (mm)	Maximum of absolute out–of-roundness[A] (mm)
16	16.0	16.3	1.2
20	20.0	20.3	1.2
25	25.0	25.3	1.2
32	32.0	32.3	1.3
40	40.0	40.4	1.4
50	50.0	50.4	1.4
63	63.0	63.4	1.5
75	75.0	75.5	1.6
90	90.0	90.6	1.8
110	110.0	110.7	2.2
125	125.0	125.8	2.5
140	140.0	140.9	2.8
160	160.0	161.0	3.2
180	180.0	181.1	3.6
200	200.0	201.2	4.0
225	225.0	226.4	4.5
250	250.0	251.5	5.0
280	280.0	281.7	9.8
315	315.0	316.9	11.1
355	355.0	357.2	12.5
400	400.0	402.4	14.0
450	450.0	452.7	15.6
500	500.0	503.0	17.5
560	560.0	563.4	19.6
630	630.0	633.8	22.1
710	710.0	716.4	24.9
800	800.0	817.2	28.0
900	900.0	908.1	31.5
1000	1000.0	1009.0	35.0

[A] Values are consistent with ISO 14531-1.

TABLE 2 Outside Diameters and Tolerances for NPS PEX Pipe

NPS	Average Outside Diameter in.	Tolerances for Average Diameter (±) in.	Maximum of absolute out–of-roundness[A] in.
3	3.500	0.016	0.07
4	4.500	0.020	0.09
5	5.563	0.025	0.11
6	6.625	0.030	0.13
8	8.625	0.039	0.17
10	10.750	0.048	0.22
12	12.750	0.057	0.26
14	14.000	0.063	0.28
16	16.000	0.072	0.40
18	18.000	0.081	0.54
20	20.000	0.090	0.60
22	22.000	0.099	0.66
24	24.000	0.108	0.72
26	26.000	0.117	0.78
28	28.000	0.126	0.98
30	30.000	0.135	1.05
32	32.000	0.144	1.12
34	34.000	0.153	1.19
36	36.000	0.162	1.26
42	42.000	0.189	1.47
48	48.000	0.216	1.68
54	54.000	0.243	1.89

[A] Values are consistent with ISO 14531-1

4. Pipe Classification

4.1 *General*—This specification covers two PEX pipe material designations – PEX 80 with an MRS of 8.0 MPa and

TABLE 3 Minimum Wall Thicknesses for DN size PEX Pipe

All dimensions in mm[A]							
DN Size	DR 6	DR 7.4	SDR 9	SDR 11	DR 13.6	DR 16.2	SDR 17
16	3.0	2.3	2.0	...	...	...	...
20	3.4	3.0	2.3	2.0	...	...	...
25	4.2	3.5	3.0	2.3	2.0	...	...
32	5.4	4.4	3.6	3.0	2.4	2.0	2.0
40	6.7	5.5	4.5	3.7	3.0	2.5	2.4
50	8.3	6.9	5.6	4.6	3.7	3.1	2.9
63	10.5	8.6	7.1	5.8	4.7	3.9	3.7
75	12.5	10.3	8.4	6.8	5.6	4.6	4.4
90	15.0	12.3	10.1	8.2	6.7	5.6	5.3
110	18.3	15.1	12.3	10.0	8.1	6.8	6.5
125	20.8	17.1	14.0	11.4	9.2	7.7	7.4
140	23.3	19.2	15.7	12.7	10.3	8.7	8.2
160	26.6	21.9	17.9	14.6	11.8	9.9	9.4
180	29.9	24.6	20.1	16.4	13.3	11.1	10.6
200	33.2	27.4	22.4	18.2	14.7	12.4	11.8
225	37.4	30.8	25.2	20.5	16.6	13.9	13.2
250	41.5	34.2	27.9	22.7	18.4	15.5	14.7
280	46.5	38.3	31.3	25.4	20.6	17.3	16.5
315	52.3	43.1	35.2	28.6	23.2	19.5	18.5
355	59.0	48.5	39.7	32.2	26.1	21.9	20.9
400	...	54.7	44.7	36.3	29.4	24.7	23.5
450	...	61.5	50.3	40.9	33.1	27.8	26.5
500	...	...	55.8	45.4	36.8	30.9	29.4
560	...	...	62.5	50.8	41.2	34.6	32.9
630	...	...	70.3	57.2	46.3	38.9	37.0
710	...	...	79.3	64.5	52.2	43.9	41.8
800	...	...	89.3	72.6	58.8	49.4	47.0
900	...	...	...	81.7	66.2	56.6	52.9
1000	...	...	...	90.2	72.5	61.8	58.8

[A] Small pipe diameters have minimum wall thicknesses values greater than the calculated value based on DR or SDR.

TABLE 4 Minimum Wall Thicknesses for NPS PEX Pipe

All dimensions in inches[A]								
NPS	DR 7.3	DR 8.3	SDR 9	SDR 11	DR 13.5	DR 15.5	SDR 17	SDR 21
3	0.479	0.422	0.389	0.318	0.259	0.226	0.206	0.167
4	0.616	0.542	0.500	0.409	0.333	0.290	0.265	0.214
5	0.762	0.670	0.618	0.506	0.412	0.359	0.327	0.265
6	0.908	0.798	0.736	0.602	0.491	0.427	0.390	0.315
8	1.182	1.039	0.958	0.784	0.639	0.556	0.507	0.411
10	1.473	1.295	1.194	0.977	0.796	0.694	0.632	0.512
12	1.747	1.536	1.417	1.159	0.944	0.823	0.750	0.607
14	1.918	1.687	1.556	1.273	1.037	0.903	0.824	0.667
16	2.192	1.928	1.778	1.455	1.185	1.032	0.941	0.762
18	2.466	2.169	2.000	1.636	1.333	1.161	1.059	0.857
20	...	2.409	2.222	1.818	1.481	1.290	1.176	0.952
22	...	...	2.444	2.000	1.630	1.419	1.294	1.048
24	...	...	2.667	2.182	1.778	1.548	1.412	1.143
26	...	...	...	2.364	1.926	1.677	1.529	1.238
28	...	...	...	2.545	2.074	1.806	1.647	1.333
30	...	...	...	2.727	2.222	1.935	1.765	1.429
32	...	...	...	2.909	2.370	2.065	1.882	1.524
34	...	...	...	3.091	2.519	2.194	2.000	1.619
36	...	...	...	3.273	2.667	2.323	2.118	1.714
42	...	...	...	...	...	2.710	2.471	2.000
48	...	...	...	...	...	3.097	2.824	2.286
54	...	...	...	...	...	...	3.176	2.571

[A] Small pipe diameters have minimum wall thicknesses values greater than the calculated value based on DR or SDR

PEX 100 with an MRS of 10.0 MPa. The maximum operating pressure (MOP) for PEX pipe is based on the MRS or CRS and shall be determined in accordance with the equations in 3.2.7.

NOTE 2—The CRS for PEX pipe is only determined after the MRS is established.

TABLE 5 Material Designation For PEX Pipe

Material Designation	MRS (20 °C and 50 years) MPa
PEX 80	8.0
PEX 100	10.0

4.2 *Operating Temperature Range*—The determination of the minimum operating temperature shall be in accordance with 6.10. The maximum operating temperature is based on the maximum temperature at which a CRS is determined by the pipe manufacturer or is listed in PPI TR-4, but not greater than 93 °C, as specified in 5.2. Operating temperatures higher than 93 °C require special design considerations – consult with the manufacturer.

5. Material Requirements

5.1 *General*—Crosslinked polyethylene materials meeting the requirements specified in Section 5, are primarily defined by means of color, UV protection, density, degree of crosslinking, and long-term strength tests specified in Section 6.

5.2 *Material Performance and MRS/CRS Requirements:*

5.2.1 PEX pipe shall be made from polyethylene materials meeting the MRS requirements of 4.1, which have been crosslinked during the pipe manufacturing process, such that the pipe meets the performance requirements of Section 6.

5.2.2 To establish the maximum operating temperature, the manufacturer shall determine the CRS at that temperature, as discussed in Appendix X2. The PEX pipe shall have a 60 °C CRS at 50 years of at least 5.0 MPa.

NOTE 3—CRS times can range from 5 years to 100 years, and CRS temperatures can range from 0 °C to 93 °C.

5.3 *Color*—Pipe made in accordance with this specification is permitted to be colored using any commercially available colorant. Pipe made in accordance with this specification is also permitted to contain no colorant.

5.3.1 Pipe made in accordance with this specification is permitted to have co-extruded PEX color stripes or PEX layers of differing colors from the primary color of the PEX pipe. These stripes or layers are on the OD of the pipe.

5.3.2 The PEX material used in the stripe or layer shall be the same type material as specified in 5.2 for the PEX pipe. If PEX pipe is to have colored stripes or colored layer, the MRS testing specified in 5.2 shall be conducted on pipe samples with colored stripes or colored layer.

NOTE 4—Choice of color for stripes or pipe is subject to the end use application of the pipe.

5.4 *UV Protection:*

5.4.1 If the carbon black content in the pipe is less than 2.0 %, the pipe shall be weathered in accordance with Test Method F2657, Practice D2565 or ISO 14531-1 Annex C. After PEX pipe has been weathered, it shall meet the thermal stability, 95 °C hydrostatic strength, and elongation at break requirements of ISO 14531-1, Table 8.

NOTE 5—Generally, the acceleration factor for accelerated weathering is between 3.75 to 4.4 times the number of test hours.

5.4.2 The UV requirement of 5.4.1 is not applicable if the content of well-dispersed carbon black, such as N110 or N550, is greater than 2.0 % and less than 3.0 % as measured by Test Method D1603 or Test Method D4218 (see ISO 14531-1 Table 8). To demonstrate good carbon black dispersion the PEX pipe shall meet the ISO 14531-1 dispersion requirement of less than or equal to grade 3 when measured in accordance with ISO 18553, or in accordance with an equivalent ASTM test method for carbon black dispersion, such as Test Method D5596.

5.4.3 Pipe intended for chlorinated potable water applications, shall first be weathered in accordance with 5.4.1 using the complete requirements of Test Method F2657, and then shall meet the requirements of 6.8.

5.5 *Density*—When determined in accordance with 7.5, the polyethylene compound prior to crosslinking shall have a minimum density of 0.926 g/cc.

6. Pipe Requirements

6.1 *Workmanship*—The materials, procedure for mixing, and the pipe process for crosslinking shall result in a product with MRS values at 20 °C and 50 years as shown in Table 5, when conditioned in accordance with 7.1 and determined in accordance with procedures no less restrictive than those of ISO 9080 or PPI TR-3. Table 6 provides design stress values for each MRS pipe material designation using the minimum overall design coefficient of 1.25 for water at 20 °C and 50 years. The design engineer shall also take into consideration the effect of the environment on the overall design coefficient. The pipe shall be homogeneous throughout and free of visible cracks, holes, foreign inclusions, or other defects. The pipe shall be as uniform as commercially practicable in color, opacity, density, and other physical properties.

6.2 *Diameters and Tolerances:*

6.2.1 *Outside Diameters*—The outside diameters and tolerances shall be as shown in Table 1 for DN sizes or Table 2 for NPS, when measured in accordance with 7.4 and 7.4.1.

6.2.2 *Out-of Roundness*—The out-of-roundness of pipe made in accordance with this specification shall be less than or equal to the values specified in Table 1 or Table 2 when measured in accordance with Test Method D2122 or ISO 3126.

6.3 *Wall Thickness and Tolerances*—The wall thickness for pipe made in accordance with this specification shall be as shown in Table 3 for DN sizes and in Table 4 for NPS, when measured in accordance with 7.4.2. The tolerance for all wall thicknesses is plus 12 %.

NOTE 6—Small pipe diameters have minimum wall thicknesses values greater than the calculated value based on DR or SDR.

6.4 *Hydrostatic Sustained Pressure Strength*—Pipe samples tested in accordance with 7.6 shall not fail as defined in Test Method D1598.

TABLE 6 PEX Pipe Design Stress at 20 °C

Material Designation	Design Stress for Water (MPa) (C = 1.25)
PEX 80 (MRS = 8 MPa)	6.4
PEX 100 (MRS = 10 MPa)	8.0

6.4.1 The test pressure (P) is based on the following equation:

$$P = 2S/(D_o/t - 1) \quad (6)$$

where:

P = Test pressure, MPa
S = Hoop stress per Table 7
D_o = outside diameter per Table 1 or Table 2
t = minimum wall thickness, per Table 3 or Table 4

6.5 *Environmental Stress Cracking*—There shall be no loss of pressure in the pipe when tested in accordance with 7.7.

6.6 *Degree of Crosslinking:*

6.6.1 When tested in accordance with 7.8, the degree of crosslinking for PEX pipe shall meet the following specified requirements before installation. The minimum percentage crosslinking value shall be 65 % for PEX compounds crosslinked using silanes or radiation, or 70 % for PEX compounds crosslinked using peroxides. The maximum degree of crosslinking shall be 89 % for all PEX types.

6.6.2 In addition, for pipe with a wall thickness greater than 0.5 in. or 12.7 mm, the degree of crosslinking shall be measured at four points separated by 90° in the middle of the wall. For one of these points, measurements shall be taken at three points across the wall thickness. Fig. 1 shows the locations where the gel content samples shall be collected relative to each other. Collect shaving samples, about 0.10 mm thick, by drilling a hole in the axial pipe direction with a 3-mm drill bit to collect a 0.2 – 0.4 gram sample size.

6.6.3 The degree of crosslinking at each of the tested points of all thick-wall pipe tested per 6.6.2 shall meet the requirements specified in 6.6.1

6.7 *Stabilizer Functionality*—The functionality of a stabilizer in a specific PEX compound shall be verified by hydrostatic testing of pipe made from the compound when tested in accordance with 7.9.

6.8 *Oxidative Stability in Chlorinated Water Applications*—PEX pipe intended for use in the transport of potable water shall have a minimum extrapolated time-to-failure of 50 years when tested at one of three exposure conditions, in accordance with 7.10, to determine the chlorine resistance level – CR1, CR3 or CR5.

6.9 *Bent Pipe Hydrostatic Sustained Pressure Strength:*

6.9.1 *General*—PEX pipe, up to and including DN 25, shall meet the requirements of 6.9.2.

NOTE 7—PEX pipe larger than DN 25 is typically installed for main distribution lines and is installed in straight runs. Fittings are used when a change in direction of 90° or greater and a bend radius of <6 times the

TABLE 7 Hoop Stress Values for Hydrostatic Sustained Pressure Test

Temperature °C	Material Designation for Pipe	Hoop Stress[A] MPa
20	PEX 80	8.3
20	PEX 100	10.4
95	PEX 80	3.7
95	PEX 100	4.7

[A]Hoop stress (MPa) values are consistent with ISO 14531-1

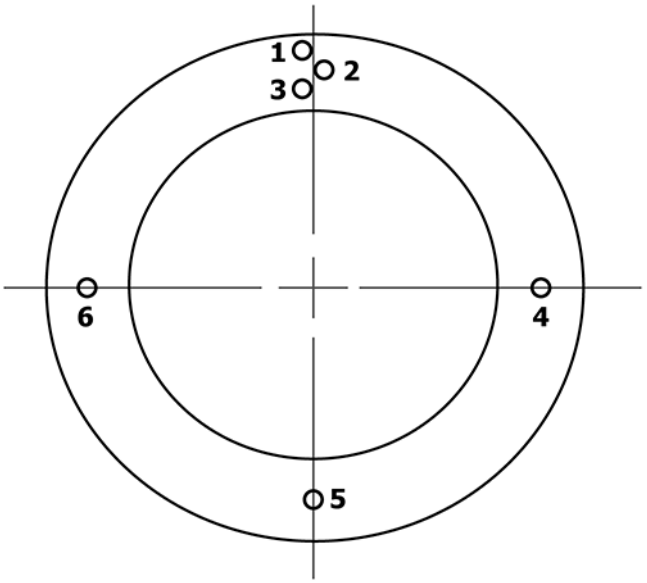

FIG. 1 Sample Location For Degrees Of Crosslinking Test On Thick-Wall Pipe

outside diameter is needed. The test procedures in 6.9.2 are intended to evaluate PEX pipe installed in tight bend applications as discussed in X3.2.5 and X3.2.6. This application applies to pipe up to and including DN 25 nominal diameter only.

6.9.2 Hot-bent pipe, with a bend radius of 2.5 times the outside diameter, and cold-bent pipe, with a bend radius of 6 times the outside diameter, and each having a continuous bend inducing not less than a 90° angle, shall meet the minimum hydrostatic sustained pressure strength requirements for 95 °C as shown in Table 7 when tested in accordance with 7.6. The bend length and bend angle is maintained throughout the testing period by rigid supports immediately outside the bend.

6.10 *Pipe Minimum Operating Temperature:*

6.10.1 The minimum operating temperature for pipe shall be established by testing in accordance with 6.10.2.

6.10.1.1 These tests to establish minimum operating temperature need only be performed for the original pipe made from a particular compound. Re-testing is required for a compound change that also requires re-testing of the new formulation as defined in PPI TR-3.

6.10.2 Determine the Small-Scale-Steady-State (S-4) RCP critical temperature in accordance with ISO 13477 at a constant hoop stress of 6.4 MPa for PEX 80 or 8.0 MPa for PEX 100 on a single pipe size, such as DN 110 pipe. The minimum operating temperature shall be equal to the S-4 critical temperature.

6.11 *Squeeze-off*—The squeeze-off testing discussed below is only for pipe sizes, wall thicknesses, squeeze procedures, and conditions deemed suitable for squeeze-off in service by the pipe manufacturer. The PEX pipe shall be conditioned to assure it is at the minimum operating temperature, then squeezed-off at this temperature in accordance with ISO 14531-1 Annex D. Samples of pipe that have been subjected to squeeze-off shall then not fail when tested at 95 ºC for 1000 hours in accordance with Test Method D1598 or ISO 1167 at the hoop stress stated in Table 7 for the material.

6.12 *Hydrostatic Burst Pressure/Apparent Tensile Strength:*

6.12.1 The minimum burst hoop stress shall be 17.4 MPa for PEX pipe with an MRS of 8 MPa or 20.0 MPa for PEX pipe with an MRS of 10 MPa, when determined in accordance with 7.11. The minimum burst pressure is based on the equation in 6.4.1. For most of the pipe sizes, average OD/minimum wall is equal to the DR or SDR. For the smaller pipe sizes, the calculated value is slightly lower than the DR or SDR value, and this will result in a slightly higher burst pressure.

6.12.2 For pipe sizes of DN 110 and larger or NPS 4 and larger testing in accordance with 7.12 is permitted to replace testing in accordance with 7.11. The minimum apparent tensile strength at yield when determined in accordance with 7.12 shall be 17.4 MPa for PEX pipe with an MRS of 8 MPa or 20.0 MPa for PEX pipe with an MRS of 10 MPa.

6.13 *Qualification of PEX Pipe for Use with Polyethylene Electrofusion Joints*—For PEX pipe that is deemed suitable by the pipe manufacturer for joining to polyethylene (PE) electrofusion fittings, the pipe manufacturer shall qualify the PEX pipe by testing joints made with PE electrofusion fittings and PEX pipe meeting this standard, and assuring that these joints meet the performance requirements of the PE electrofusion fitting standard, such as Specification F3373. The pipe shall then be marked in accordance with 8.2.9.

7. Test Methods

7.1 *Conditioning*—Unless otherwise specified, condition the specimens for not less than 40 h prior to testing in accordance with Procedure A of Practice D618, for those tests where conditioning is required. In cases of disagreement, the tolerances shall be ±1 °C and ±10 % relative humidity. Peroxide-crosslinked PEX pipe samples intended for sustained pressure or ISO 9080 testing shall be conditioned at the specified test temperature with an internal pressure equal to the MOP for a specified time to achieve the pipe's full strength – consult with the pipe manufacturer for their test conditioning recommendations.

7.2 *Test Conditions*—Conduct the test in the standard laboratory atmosphere, unless otherwise specified in the test methods or in this specification. In cases of disagreement, the tolerances shall be ±1 °C and ±10 % relative humidity.

7.3 *Sampling*—A sufficient quantity of pipe, as agreed upon by the purchaser and the seller, shall be selected and tested to determine conformance with this specification. In the case of no prior agreement, random samples selected by the testing laboratory shall be deemed adequate.

7.3.1 *Test Specimens*—Not less than 50 % of the test specimens required for any pressure test shall have at least a part of the marking in their central sections. The central section is that portion of pipe that is at least one pipe diameter away from an end closure.

7.4 *Dimensions and Tolerances*—Use any length of pipe to determine the dimensions. Measurements shall be taken in accordance with Test Method D2122 or ISO 3126.

7.4.1 *Outside Diameter*—Measure the outside diameter of the pipe in accordance with Test Method D2122 or ISO 3126

at 300 mm from the pipe end. The referee method of measurement is to be by circumferential wrap tape. The tolerance for out-ofroundness shall apply only to pipe prior to shipment. The average of four (4) maximum and minimum diameter measurements at any cross section, measured by micrometer or vernier caliper, is permitted for quality control checks only.

7.4.2 *Wall Thickness*—Make micrometer measurements of the wall thickness in accordance with Test Method D2122 or ISO 3126 to determine the maximum and minimum values. Measure the wall thickness at both ends of the pipe to the nearest 0.001 in. or 0.025 mm.

7.5 *Density*—Determine the density of the pipe compound in accordance with Test Method D1505 or Test Methods D792, using three specimens.

7.6 *Hydrostatic Sustained Pressure Test*—Condition pipe specimens in accordance with 7.1. The size of pipe sampled for this test shall be less than or equal to NPS 4 or DN 110. Select the test specimens at random. Test individually with water at the specified temperature and under the pressures given in 6.4. Each specimen shall be at least ten times the nominal diameter in length, but not more than 900 mm between end closures and containing the permanent marking on the pipe. Test six specimens at each temperature. Condition the specimens for at least 2 h to within ± 2 °C of the specified test temperatures. Maintain the specimens at the stresses indicated in Table 7 for the appropriate temperatures for a period of 1000 h. Hold the stress as closely as possible, but within ± 0.1 MPa. Maintain the test temperatures within ± 2 °C of the specified temperature. Test in accordance with Test Method D1598 or ISO 1167 except maintain the pressure at the values given in 6.5 for 1000 h. Failure of one of six specimens tested at either temperature constitutes failure in the test.

7.7 *Environmental Stress Cracking Test*—Test five randomly selected minimum 300-mm long specimens of DN 16, 20 or 25 pipe made in accordance with this specification. The tubing specimens shall be straight, that is not cut from a coil.

7.7.1 Make a notch on the inside of the pipe wall in the axial direction. The notch depth shall be 10 % of the minimum wall thickness and the depth tolerance shall be 10 % of the wall thickness tolerance both as specified in Table 3 or Table 4. The notch length shall be 25 +5 mm. Use a sharp blade mounted in a jig to make the notch. Use a depth micrometer or other means for setting the blade in the jig so that the notch depth is controlled as specified. The notch shall be placed, at its nearest point, at least 1.5 times the nominal diameter away from end closures.

7.7.2 Fill the pipe with the test medium which is 5 % nonylphenoxy poly(ethyeneoxy) ethanol (CAS# 68412-54-4, for example "Igepal CO-630"[7]) mixed with 95 % water. Test the specimens in accordance with Test Method D1598 at 95 °C at a hoop stress of 3.7 MPa for PEX 80 or 4.7 MPa for PEX 100 for 100 h. Testing in accordance with Test Method D1598 shall be conducted with the exception that the testing is not required to be carried out until specimen failure as defined in Test Method D1598.

NOTE 8—There are environmental concerns regarding the disposal of nonylphenoxy poly(ethyleneoxy) ethanol (CAS 68412- 54-4). Users are advised to consult their supplier or local environmental office.

7.8 *Degree of Crosslinking*—Prepare specimens by placing a pipe sample in a lathe with automatic feeding. Shave strips that consist of the full wall thickness of the pipe. The strip thickness shall be 0.1 ± 0.05 mm, which is obtained by setting the lathe feeding accordingly. Test the specimens in accordance with Test Methods D2765, Method B. Alternatively, for routine quality control and monitoring only, testing in accordance with Test Method F3203 is permissible. For either test method the only deviation permitted is test specimen preparation which shall be as specified above. In the case of a pipe wall thickness greater than 0.5 in or 13 mm alternative specimens per 6.6.2 shall also be tested. For the purpose of this specification the degree of crosslinking is equal to the measured gel content.

7.9 *Stabilizer Functionality*—Test six pipe samples of PEX 80 or PEX 100 continuously for 3000 h at a hoop stress of 0.70 MPa at 120 °C, or for 8000 h at a hoop stress of 2.8 MPa at 110 °C.

NOTE 9—This test is used to demonstrate the specific compound's ability to withstand long-term temperature conditions set forth in this standard.

7.9.1 Test in accordance with Test Method D1598 or ISO 1167. Test six samples at one of the temperature and hoop stress conditions in 7.9. The internal medium shall be water the external medium shall be air. Failure of any one of the specimens constitutes failure of the test.

7.9.2 *Significance*—The test shall be performed for the first use of pipe made from a particular compound.

7.10 *Oxidative Stability in Chlorinated Water Applications*—The test shall be conducted, and the extrapolated time-to-failure shall be determined in accordance with Test Method F2023.

7.10.1 For a chlorine resistance of "CR1" a minimum extrapolated time-to-failure of 50 years at temperature exposure conditions of 25 % of the total time at 60 °C and 75 % of the total time at 23 °C in accordance with Test Method F2023.

7.10.2 For a chlorine resistance of "CR3" a minimum extrapolated time-to-failure of 50 years at temperature exposure conditions of 50 % of the total time at 60 °C and 50 % of the total time at 23 °C in accordance with Test Method F2023.

7.10.3 For a chlorine resistance of "CR5" a minimum extrapolated time-to-failure of 50 years at a temperature exposure condition of 100 % of the time at 60 °C.

NOTE 10—The conditions described in Test Method F2023, only apply to intermittent service such as might be found in normal residential use. This does not validate the use of PEX pipe in continuous recirculation applications.

7.10.4 *Significance*—The test need only be performed on representative pipe samples for the original validation of pipe made from a particular compound.

7.11 *Hydrostatic Burst Pressure*—Determine the minimum burst pressure with at least five specimens in accordance with

[7] This method is based on the use of "Igepal Co-630," a trademark for a nonylphenoxypoly (ethyeneoxy) ethanol, which may be obtained from GAF Corp., Dyestuff and Chemical Div., 140 W. 51st St., New York, NY 10020.