



Standard Specification for Crosslinked Polyethylene/Aluminum/Crosslinked Polyethylene (PEX-AL-PEX) Pressure Pipe¹

This standard is issued under the fixed designation F 1281; 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 a coextruded crosslinked polyethylene composite pressure pipe with a welded aluminum tube reinforcement between the inner and outer layers. The inner and outer crosslinked polyethylene layers are bonded to the aluminum tube by a melt adhesive. Included is a system of nomenclature for the crosslinked polyethylene-aluminum-crosslinked polyethylene (PEX-AL-PEX) pipes, the requirements and test methods for materials, the dimensions of the component layers and finished pipe, adhesion tests, and the burst and sustained pressure performance. Also given are the requirements and methods of marking. The pipe covered by this specification is intended for use in potable water distribution systems for residential and commercial applications, water service, underground irrigation systems, and radiant panel heating systems, baseboard, snow- and ice-melt systems, and gases that are compatible with the composite pipe and fittings.

1.2 This specification covers only composite pipes incorporating a welded aluminum tube. Pipes consisting of metallic layers not welded together are outside the scope of this specification.

1.3 Specifications for connectors for use with pipe meeting the requirements of this specification are given in **Annex A1**.

1.4 This specification excludes polyethylene-aluminum-polyethylene pipes (see Specification **F 1282**).

1.5 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.6 The following precautionary caveat pertains only to the test methods portion, Section 9, of this specification: *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 and health practices and determine the applicability of regulatory limitations prior to use.*

¹ This specification is under the jurisdiction of ASTM Committee F17 on Plastic Piping Systems and is the direct responsibility of Subcommittee F17.11 on Composite.

Current edition approved May 1, 2007. Published May 2007. Originally approved in 1990. Last previous edition approved in 2005 as F 1281 – 05.

2. Referenced Documents

2.1 ASTM Standards:²

- D 618** Practice for Conditioning Plastics for Testing
 - D 883** Terminology Relating to Plastics
 - D 1598** Test Method for Time-to-Failure of Plastic Pipe Under Constant Internal Pressure
 - D 1599** Test Method for Resistance to Short-Time Hydraulic Pressure of Plastic Pipe, Tubing, and Fittings
 - D 1600** Terminology for Abbreviated Terms Relating to Plastics
 - D 1898** Practice for Sampling of Plastics³
 - D 2122** Test Method for Determining Dimensions of Thermoplastic Pipe and Fittings
 - D 2765** Test Methods for Determination of Gel Content and Swell Ratio of Crosslinked Ethylene Plastics
 - D 3350** Specification for Polyethylene Plastics Pipe and Fittings Materials
 - E 8** Test Methods for Tension Testing of Metallic Materials
 - F 412** Terminology Relating to Plastic Piping Systems
 - F 1282** Specification for Polyethylene/Aluminum/Polyethylene (PE-AL-PE) Composite Pressure Pipe
 - F 1974** Specification for Metal Insert Fittings for Polyethylene/Aluminum/Polyethylene and Crosslinked Polyethylene/Aluminum/Crosslinked Polyethylene Composite Pressure Pipe
- ### 2.2 National Sanitation Foundation Standard:
- Standard No. 61** Drinking Water System Components—Health Effects⁴
 - Standard No. 14** Plastics Piping System Components and Related Materials⁴
- ### 2.3 Federal Standard:
- Fed. Std. No. 123** Marking for Shipments (Civil Agencies)⁵

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.

³ Withdrawn.

⁴ Available from the NSF International, 789 N. Dixboro Rd., Ann Arbor, MI 48113-0140.

⁵ Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5098, Attn: NPODS.

TABLE 1 Outside Diameters, Aluminum Thickness, and Tolerances for PEX-AL-PEX

Nominal Pipe Size, mm (in.)	Minimum Outside Diameter, mm (in.)	Tolerance on Minimum, mm (in.)	Maximum Out-of- Roundness, ^A mm (in.)	Minimum Aluminum Thickness, mm (in.)	Tolerance on Thickness, mm (in.)
0912 (3/8)	12.00 (0.472)	+0.30 (0.012)	0.3 (0.012)	0.18 (0.007)	+0.09 (+0.0035)
1216 (1/2)	16.00 (0.630)	+0.30 (0.012)	0.4 (0.016)	0.18 (0.007)	+0.09 (+0.0035)
1620 (5/8)	20.00 (0.787)	+0.30 (0.012)	0.5 (0.020)	0.23 (0.009)	+0.09 (+0.0035)
2025 (3/4)	25.00 (0.984)	+0.30 (0.012)	0.5 (0.020)	0.23 (0.009)	+0.09 (+0.0035)
2532 (1)	32.00 (1.260)	+0.30 (0.012)	0.5 (0.020)	0.28 (0.011)	+0.09 (+0.0035)
3240 (1 1/4)	40.10 (1.579)	+0.30 (0.012)	0.5 (0.020)	0.33 (0.013)	
4150 (1 1/2)	50.10 (1.972)	+0.30 (0.012)	0.5 (0.020)	0.47 (0.018)	
5163 (2)	63.10 (2.484)	+0.40 (0.016)	0.5 (0.020)	0.57 (0.022)	
6075 (2 1/2)	75.10 (2.957)	+0.60 (0.024)	1.0 (0.039)	0.67 (0.026)	

^A The out-of-roundness specification applies only to tubing prior to coiling.

2.4 Military Standard:

MIL-STD-129 Marking for Shipment and Storage⁵

2.5 Uniform Classification Committee Standard:

Uniform Freight Classification⁶

2.6 National Motor Freight Traffic Association Standard:

National Motor Freight Classification⁷

3. Terminology

3.1 Definitions—Definitions are in accordance with Terminology **F 412**, and abbreviations are in accordance with Terminology **D 1600**, unless otherwise specified.

3.2 Definitions of Terms Specific to This Standard:

3.2.1 assembly—the joint between a fitting and a length of pipe.

3.2.2 PEX-AL-PEX pipe—composite pipe produced by co-extrusion or extrusion of layers of polyethylene/aluminum/polyethylene bonded together with a melt adhesive and crosslinked by irradiation or chemical means in combination heat and moisture.

3.2.3 pipe hoop stress—for simplicity the value of the hoop stress quoted assumes a homogeneous wall. Local values of stress will vary with the different layers (see 3.2.3.1).

3.2.3.1 Discussion—Thick walled plastic pipes produced from one material have hoop stresses that vary through the wall, and are usually described by the Lamé Theory. The composite nature of the PEX-AL-PEX pipe, composed of materials with very different Young's Modulus values, will, on pressurization, not have a uniform stress distribution through the thickness of the wall of the pipe. The PEX-AL-PEX pipes have a hoop stress distribution that differs substantially from both the thick and thin walled pipe cases.

4. Pipe Classification

4.1 Pipe Diameter—The PEX-AL-PEX pipes are classified by the outside diameter.

4.2 Pipe Dimension Ratio—The concept of dimension ratio is not relevant to PEX-AL-PEX composite pipes, and cannot be used to relate pressure rating with total wall thickness.

5. Materials

5.1 General—The PEX-AL-PEX pipe is composed of one metallic layer, two layers of polymeric adhesive, and two

layers of crosslinked polyethylene. For pipe made to this specification the constituent materials must meet the following requirements:

5.2 Aluminum—The aluminum shall have a thickness as specified in **Table 1**. The material shall have minimum elongations and ultimate tensile strengths of 20 % and 100 MPa (14 600 psi), respectively. The tests shall be conducted according to Test Methods **E 8**.

5.3 Crosslinked Polyethylene:

5.3.1 The polyethylene shall be, in the final finished state in the pipe, crosslinked as defined in Terminology **D 883**.

5.3.2 Polyethylene plastics used to make pipe meeting the requirements of this specification shall be virgin resin meeting the requirements of either Grade PE20A, B, or C; Grade PE23A, B, or C; Grade PE30A, B, or C; or Grade PE33A, B, or C in accordance with Specification **D 3350**.

5.3.3 Class B compounds shall have sufficient ultraviolet (UV) stabilizers to protect the pipe from deleterious effects due to continuous outdoor exposure during storage and shipping. Pipe produced from Class B compounds are not suitable for exposed outdoor application. Class A, B, and C compounds shall have sufficient antioxidants to meet the requirements in Specification **D 3350**.

5.4 Melt Adhesive—The material shall have a density cell of 1, 2, or 3; a melt index cell of 1, 2, or 3; and a color code of A or B, in accordance with Specification **D 3350**.

5.5 Rework Material—The use of reclaimed, recycled, or rework plastics is not permitted.

6. Requirements Requirements

6.1 General—The requirements and test methods in this specification cover PEX-AL-PEX pipes. Tests on the individual layers that comprise this composite pipe are outside the scope of this specification. The raw materials used, however, must conform to the requirements as set out in Section 5.

6.2 Dimensions and Tolerances of Pipe:

6.2.1 Pipe Diameter—The minimum outside diameter and tolerances of the pipe shall meet the requirements given in **Table 1**, when measured in accordance with **9.1** and **9.1.2**. Maximum and minimum (out-of-roundness) tolerances apply only to measurements made on pipe prior to coiling.

6.2.2 Pipe Wall Thickness—The total pipe wall thickness shall meet the requirements given in **Table 2**, when measured in accordance with **9.1** and **9.1.3**. The minimum wall thickness at any point of measurement of the pipe shall not be less than the value specified in **Table 2**.

⁶ Available from the Uniform Classification Committee, Suite 1106, 222 South Riverside Plaza, Chicago, IL 60606.

⁷ Available from the National Motor Freight Traffic Association, Inc., National Motor Freight Classification, American Trucking Associations, Inc., Traffic Dept., 1616 P St., NW, Washington, DC 20036.

TABLE 2 Wall Thickness for PEX-AL-PEX Composite Pipe

Nominal Pipe Size, mm (in.)	Total Wall Thickness, min, mm (in.)	Wall Tolerance (+) mm	Outer PE Layer Thickness, min, mm (in.)	Inner PE Layer Thickness, min, mm (in.)
0912 (3/8)	1.60 (0.063)	0.40 (0.016)	0.40 (0.016)	0.70 (0.028)
1216 (1/2)	1.65 (0.065)	0.40 (0.016)	0.40 (0.016)	0.90 (0.035)
1620 (5/8)	1.90 (0.075)	0.40 (0.016)	0.40 (0.016)	1.00 (0.039)
2025 (3/4)	2.25 (0.089)	0.50 (0.020)	0.40 (0.016)	1.10 (0.043)
2532 (1)	2.90 (0.114)	0.60 (0.024)	0.40 (0.016)	1.20 (0.047)
3240 (1 1/4)	3.85 (0.152)	0.60 (0.024)	0.40 (0.016)	1.70 (0.067)
4150 (1 1/2)	4.35 (0.171)	0.60 (0.024)	0.40 (0.016)	1.70 (0.067)
5163 (2)	5.80 (0.228)	0.60 (0.024)	0.40 (0.016)	2.05 (0.081)
6075 (2 1/2)	7.25 (0.285)	0.60 (0.024)	0.40 (0.016)	2.80 (0.110)

6.2.3 Outer Crosslinked Polyethylene Layer Thickness— The thickness of the outer layer of crosslinked polyethylene in the PEX-AL-PEX pipe shall have a minimum value and tolerance as specified in Table 2, except for the polyethylene material overlaying the weld, which shall have a minimum thickness of half that specified in Table 2. The polyethylene thickness shall be measured in accordance with 9.2.

6.2.4 Pipe Length— The pipe shall be supplied coiled or in straight lengths as agreed upon with the purchaser and with an allowable tolerance of -0 mm (-0 in.).

6.3 Adhesion Test:

6.3.1 For Sizes 0912 (3/8) to 2532 (1) there shall be no delamination of the PEX and AL, either on the bore side or the outside (see Fig. 1). The test shall be conducted in accordance

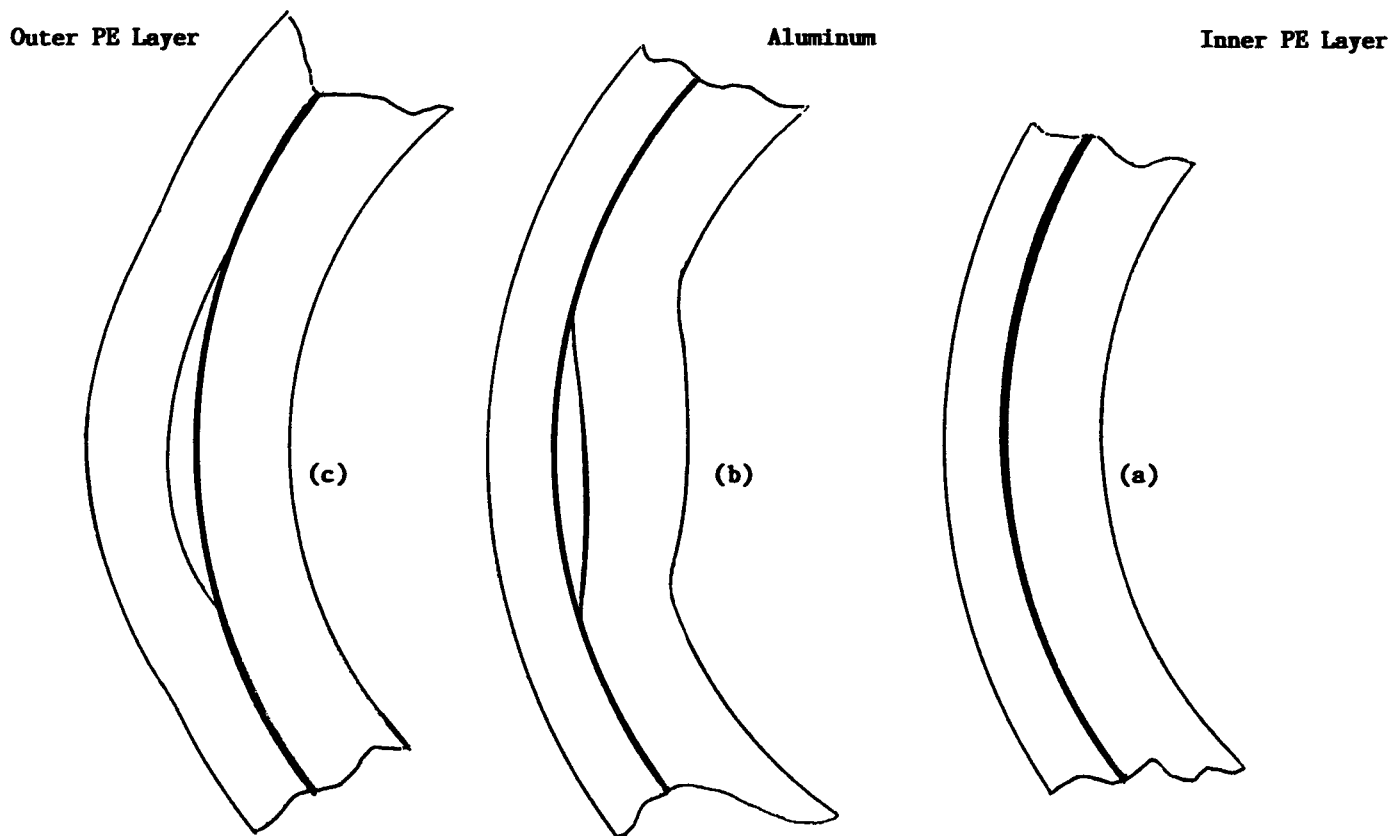
with 9.3.1.

6.3.2 The adhesion test of the PEX-layer to the aluminum for Sizes 3240 (1 1/4) to 6075 (2 1/2) is carried out by a separation test. The minimum adhesive force is specified in Table 3. The adhesive force shall not fall below these levels. The test shall be conducted in accordance with 9.3.2.

6.4 Apparent Tensile Strength of Pipe— The pipe rings, when tested in accordance with 9.4, shall meet the minimum strength specifications defined in Table 4.

6.5 Burst Pressure— The minimum burst pressure for PEX-AL-PEX pipe shall be as given in Table 4, when determined in accordance with 9.5.

6.6 Sustained Pressure— The PEX-AL-PEX pipe shall not fail, balloon, burst, or weep, as defined in Test Method D 1598,



NOTE 1—(a) Good pipe showing no delamination, (b) Delamination between the inner layer and the aluminum, and (c) Delamination between the outer layer and the aluminum.

FIG. 1 Detection of Delamination

TABLE 3 Minimum Adhesive Force for PEX-AL-PEX Composite Pipe

Nominal Pipe Size, mm (in.)	Minimum Adhesive Force per 10-mm (0.394-in.) Pipe Strip, N (lbf)
3240 (1¼)	40 (9.0)
4150 (1½)	50 (11.2)
5163 (2)	60 (13.5)
6075 (2½)	70 (15.7)

TABLE 4 Minimum Pipe Ring Strengths and 23°C (73.4°F) Burst Pressure of PEX-AL-PEX Composite Pipe

Nominal Pipe Size, mm (in.)	Minimum Pipe Ring Strength,	Minimum Pipe Ring Strength,	Minimum 23°C (73.4°F) Burst Pressure, kPa (psi)
	Type II PE, N(lb)	Type III PE, N(lb)	
0912 (¾)	2000 (448)	2100 (470)	7000 (1020)
1216 (½)	2100 (470)	2300 (515)	6000 (880)
1620 (5/8)	2400 (538)	2500 (560)	5000 (730)
2025 (¾)	2400 (538)	2500 (560)	4000 (580)
2532 (1)	2650 (598)	2500 (560)	4000 (580)
3240 (1¼)	3200 (719)	3500 (789)	4000 (580)
4150 (1½)	3500 (789)	3700 (832)	3800 (554)
5163 (2)	5200 (1169)	5500 (1236)	3800 (554)
6075 (2½)	6000 (1349)	6000 (1349)	3800 (554)

when tested for 10 h at the test at the test pressure given in [Table 5](#) at a temperature of 82°C (180°F) in accordance with [9.6](#).

6.7 Gel Content—When tested in accordance with [9.7](#), the gel content of the inner and outer tubes of crosslinked polyethylene shall have minimum values of either 65 % for the fully crosslinked silane material or 60 % for radiation crosslinked polyethylene. Test Methods [D 2765](#) defines gel content (see [Note 2](#)).

NOTE 1—The gel test is one of several methods capable of indicating the degree of crosslinking. The different methods for assessing degree of crosslinking do not necessarily agree, so conformity to this specification requires degree of crosslinking to be determined in accordance with [9.7](#) only.

7. Workmanship

7.1 The pipe shall be free of visible cracks, holes, foreign inclusions, blisters, and other known injurious defects. The pipe shall be as uniform as practicable in color, opacity, density, and other physical properties.

8. Sampling and Conditioning

8.1 Sampling—Take a sample of the PEX-AL-PEX pipe sufficient to determine conformance with this specification.

TABLE 5 Minimum Sustained Pressure for PEX-AL-PEX Composite Pipe

Nominal Pipe Size, mm (in.)	Minimum Sustained Pressure PEX-AL-PEX, kPa (psi)
0912 (¾)	2720 (395)
1216 (½)	2720 (395)
1620 (5/8)	2720 (395)
2025 (¾)	2720 (395)
2532 (1)	2720 (395)
3240 (1¼)	2000 (295)
4150 (1½)	2000 (295)
5163 (2)	2000 (295)
6075 (2½)	2000 (295)

The number of specimens designated for each test shall be taken from pipe selected at random in accordance with the random sampling plan of Practice [D 1898](#).

NOTE 2—Sample size and testing frequency of lots for quality control must be established by the manufacturer to ensure conformance to the specification. Sampling and frequency will vary with the specific circumstances.

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

8.3 Conditioning—Condition the specimens at $23 \pm 2^\circ\text{C}$ ($73.4 \pm 3.6^\circ\text{F}$) and $50 \pm 5\%$ relative humidity for not less than 40 h prior to test in accordance with Procedure A of Practice [D 618](#), for those tests where conditioning is required. In cases of disagreement, the tolerances shall be $\pm 1^\circ\text{C}$ ($\pm 1.8^\circ\text{F}$) and $\pm 2\%$ relative humidity.

8.4 Test Conditions—Conduct the test in the standard laboratory atmosphere of $23 \pm 2^\circ\text{C}$ ($73.4 \pm 3.6^\circ\text{F}$) and $50 \pm 5\%$ relative humidity, unless otherwise specified in the test methods or in this specification. In cases of disagreement, the tolerances shall be $\pm 1^\circ\text{C}$ (1.8°F) and $\pm 2\%$ relative humidity.

9. Test Methods

9.1 Dimensions and Tolerances:

9.1.1 Pipe—Any length of the PEX-AL-PEX composite pipe may be used to determine dimensions.

9.1.2 Outside Diameter—Measure the outside diameter of the PEX-AL-PEX pipe in accordance with Test Method [D 2122](#).

9.1.3 Wall Thickness—Make micrometre measurements of the wall thickness in accordance with Test Method [D 2122](#) to determine the maximum and minimum values. Measure the wall thickness at both ends of the pipe to the nearest 0.01 mm (0.0004 in.).

9.2 Outer Crosslinked Polyethylene Layer Thickness:

9.2.1 Sample Preparation—Cut the pipe with a sharp knife or other suitable cutter, ensuring that the pipe after cutting is not more than 10 % out-of-round.

9.2.2 Thickness Determination—Use a hand-held magnifying glass equipped with graduated reticule, or a laboratory microscope with graduated reticule. The reticule should measure to the nearest to 0.1 mm (0.004 in.). Determine the thickness of the outer layer of crosslinked polyethylene at six points around the circumference. One of the points only should be at the aluminum weld.

9.3 Adhesion Tests:

9.3.1 Visual Test:

9.3.1.1 Cutting the Spiral—Mount a Stanley 1991 or similarly sharp but rigid razor-like blade within a protective housing and angle to cut a $45 \pm 5^\circ$ spiral in the pipe (see [Fig. 2](#)). Choose a PEX-AL-PEX pipe at random and insert into the housing and rotate to form the spiral cut. The cut goes through the complete wall on one side of the pipe only. Run the spiral along the pipe for a minimum distance along the pipe axis equal to five times the outside diameter.

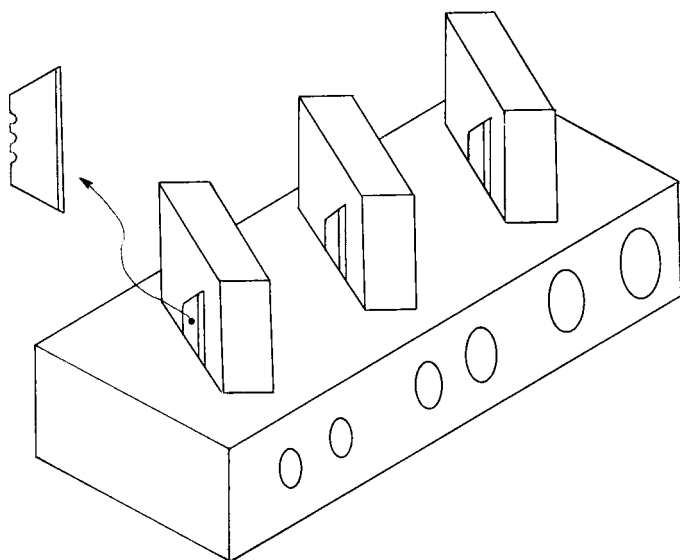


FIG. 2 Spiral Cutter for the Delamination Test

9.3.1.2 *Examining for Delamination*—Firmly hold the pipe with the spiral cut firm at the uncut end and create a ribbon of pipe material by opening out the spiral-cut pipe. Pliers can be used to grip the spiral-cut pipe. Examine the wall of the pipe visually side-on for evidence of delamination between the metal and plastic layers (see Fig. 1).

9.3.2 Separation Test:

9.3.2.1 *Specimen*—Five pipe sections of 10-mm (0.394-in.) length are cut at random intervals. The outer layers of the pipe (outer PEX-layer together with the aluminum) are separated mechanically from the inner PEX-layer with an appropriate device on the opposite side to the welding seam. The outer layers are separated on one side to about 5 mm from the pipe in order to allow clamping. The adhesion for the outer PEX-layer to the aluminum is then visually examined for delamination at the corresponding test sample.

9.3.2.2 Test Equipment:

(1) *Tension Testing Device*, with suitable pull-off device (see Fig. 3).

(2) $D_{roller} = 95\%$ of the required pipe inner diameter.

(3) d_i = pipe inner diameter.

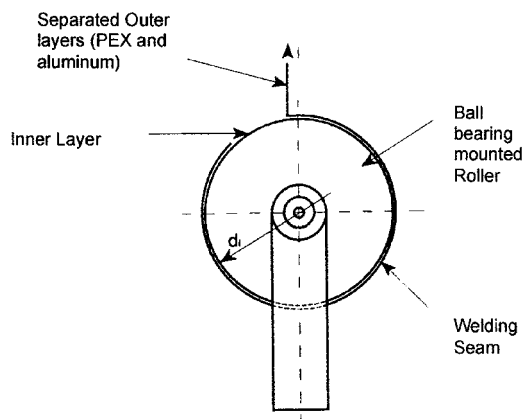


FIG. 3 Setup for Separation Test

9.3.2.3 *Test Procedure*—Remove the outer layers from the pipe at $23 \pm 2^\circ\text{C}$ ($73.4 \pm 3.6^\circ\text{F}$) with a linear speed of 50 mm/min (≈ 2 in./min). Record the force diagram.

9.4 Ring Test:

9.4.1 *Sample Size and Shape*—Cut rings of the PEX-AL-PEX pipe so that the two sides are parallel and at $90 \pm 2^\circ$ to the pipe axis. The width of each ring shall be 25 ± 1 mm (1 ± 0.04 in.). Cut a minimum of 15 samples consecutively along the axis of the pipe.

9.4.2 *Ring Tests*—Test the 15 consecutively cut samples using a tensile testing machine. Arrange the rings so that the aluminum weld is at 90° to the tensile axis as shown in Fig. 4. The crosshead speed shall be 50 ± 2.5 mm/min (2 ± 0.1 in./min). Mount the rings of pipe on two steel rods of minimum diameter of 4 mm (0.16 in.). Record the peak force.

9.5 Burst Pressure:

9.5.1 *Pipe Sample*—Select a length of PEX-AL-PEX pipe at random and prepare five consecutive lengths of 300 ± 5 mm (12 ± 0.2 in.). Seal samples at the ends with the appropriate fittings and test either free- or fixed-end.

9.5.2 *Temperature Control*—Test samples at a temperature of $23 \pm 2^\circ\text{C}$ ($73.4 \pm 3.6^\circ\text{F}$). Contain samples either in a temperature controlled water bath or in air (at standard laboratory atmosphere). For samples contained in a water bath, 1 h conditioning is required. For samples tested in air, a 16 h conditioning period is required.

9.5.3 *Burst Pressure*—Determine the burst pressure in accordance with the procedure in Test Method D 1599.

9.6 Sustained Pressure Test:

9.6.1 *Samples*—Each test sample of PEX-AL-PEX pipe shall have a minimum length between end closures of at least ten times the average outside diameter, but not less than 250 mm (10 in.). Seal specimens at both ends with the appropriate fittings and fill the samples for testing with water.

9.6.2 *Test Procedures*—Test the samples in a temperature controlled water bath or in air, in accordance with Test Method D 1598. A test temperature of $82 \pm 2^\circ\text{C}$ ($180 \pm 3.6^\circ\text{F}$) is specified. For each pipe size test six samples. For testing in a water bath, condition the test samples for at least 2 h in the

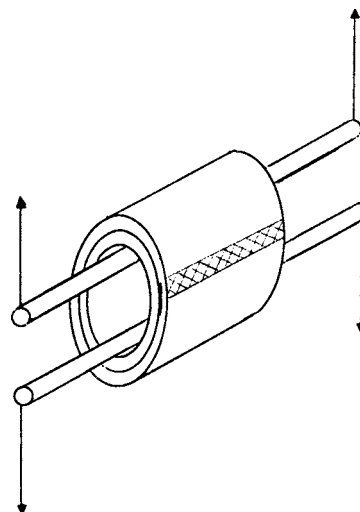


FIG. 4 Schematic Presentation of the Pipe Ring Test Showing the Aluminum Weld at 90° to the Tensile Axis

water bath at the test temperature prior to pressurization. For testing in air, condition the samples for at least 4 h in air at the test temperature prior to pressurization. Maintain the pressure at the pressure given in **Table 5** for the duration of the test.

9.6.3 Failure—Any continuous loss of pressure of the test sample shall constitute failure of the test. Failure of one of the six is cause for retest of six additional samples under identical conditions. Failure of one of six of the retested samples below the minimum specified lifetime constitutes failure of the test.

9.7 Gel Content Determination:

9.7.1 Sample Preparation—Condition the PEX-AL-PEX pipe in a water bath for a minimum of 24 h at a minimum temperature of 80°C (176°F) prior to testing to ensure full crosslinking of the resin. Before taking samples for gel content evaluation, put pipe in an air-circulating oven at 120°C (248°F) for 20 min. Using a lathe, remove 0.1-mm (0.004-in.) thick strands from the outside layer, and 0.2-mm (0.008-in.) thick strands from the inside layer, long enough to obtain a 0.3-g sample for testing. Care should be taken not to cut into the adhesive layer, as it will effect the test results. (See **Note 3**.)

9.7.2 Test Method—Test the sample from the inner and outer surface separately and in accordance with Sections 12 and 13 of Test Methods **D 2765**, Test Method A.

NOTE 3—Including the adhesive in the test specimen will lower the gel content resulting in a false reading.

10. Quality Assurance

10.1 Quality Assurance—When the product is marked with this designation, ASTM F 1281, the manufacturer affirms that

the product was manufactured, inspected, sampled, and tested in accordance with this specification and has been found to meet the requirements of this specification. When specified in the purchase order or contract, a report of the test results shall be furnished.

11. Marking

11.1 Quality of Marking—The marking shall be applied to the pipe in such a manner that it remains legible (easily read) after installation.

11.2 Markings on the tubing shall include the following, spaced at intervals of not more than 1.5 m (5 ft):

11.2.1 Nominal tubing size (for example, 1216),

11.2.2 The material designation “PEX-AL-PEX,”

11.2.3 Pressure rating for water and temperature for which the pressure rating is valid,

11.2.4 ASTM designation F 1281, with which the tubing complies, and

11.2.5 Manufacturer’s name (or trademark) and production code.

11.2.6 Tubing intended for the transport of potable water shall also include the seal or mark of the laboratory making the evaluation and the number of the standard used for the evaluation.

NOTE 4—Manufacturers using the seal or mark of a laboratory must obtain prior authorization from the laboratory concerned.

12. Keywords

12.1 composite; crosslinked PE; PEX-AL-PEX; pipe; pressure

SUPPLEMENTARY REQUIREMENTS

GOVERNMENT/MILITARY PROCUREMENT

These requirements apply *only* to Federal/Military procurement, not domestic sales or transfers.

S1. Responsibility for Inspection—Unless otherwise specified in the contract or purchase order, the producer is responsible for the performance of all inspection and test requirements specified herein. The producer may use his own or any other suitable facilities for the performance of the inspection and test requirements specified herein, unless disapproved by the purchaser. The purchaser shall have the right to perform any of the inspections and tests set forth in this specification where such inspections are deemed necessary to ensure that material conforms to prescribed requirements.

NOTE S1.1—In U. S. Federal Government contracts, the contractor is responsible for inspection.

S2. Packaging and Marking for U. S. Government Procurement:

S2.1 Packaging—Unless otherwise specified in the contract, the material shall be packaged in accordance with the supplier’s standard practice in a manner ensuring arrival at destination in a satisfactory condition and that will be acceptable to the carrier at lowest rates. Containers and packaging shall comply with Uniform Freight Classification rules or National Motor Freight Classification rules.

S2.2 Marking—Marking for shipment shall be in accordance with **Fed. Std. No. 123** for civil agencies and **MIL-STD-129** for military agencies.

NOTE S1.2—The inclusion of U. S. Federal Government procurement requirements should not be construed as an indication that the U. S. Government uses or endorses the products described in this specification.



POTABLE WATER REQUIREMENT

This requirement applies whenever a Regulatory Authority or user calls for product to be used to convey or be in contact with potable water.

S3. Products intended for contact with potable water shall be evaluated, tested and certified for conformance with ANSI/NSF **Standard No. 61** or the health effects portion of NSF

Standard No. 14 by an acceptable certifying organization when required by the regulatory authority having jurisdiction.

CHLORINE RESISTANCE EVALUATION

The following supplemental requirements shall apply to any product intended to be used in a water system which utilizes residual free chlorine as a disinfecting agent.

S4. *Evaluation Methodology*—Multi-layer (composite) piping shall be tested and evaluated in accordance with S5 for multi-layer products using PEX materials that were tested in a solid-wall form.

S5. *Procedure for Using Data from Solid-wall PEX Testing*—The 95 % lower confidence limit of the multi-layer piping product minimum estimated failure time shall be at least 50 years when evaluated in accordance with S5.1–S5.3 using conditions of 0.55 MPa (80 psig) internal pressure, 25 % use at 60°C (140°F) and 75 % use at 23°C (73°F).

S5.1 *PEX Material Test*—The PEX material shall be tested in accordance with Test Method F 2023 using solid-wall pipe samples.

S5.1.1 The test fluid shall be prepared in accordance with 9.1.1 of F 2023.

S5.1.2 The regression analysis shall be performed in accordance with, and comply with the requirements of Section 13 Calculation, F 2023.

S5.2 *Application to Multi-layer Construction*—Testing of the multi-layer product shall be conducted as specified in S5.2.1–S5.2.7.

S5.2.1 Determine the sizes of pipe for testing. Two sizes are required, such that one size has the inner-layer dimension ratio ($ILDR = OD_{\text{inner layer}} / t_{\text{inner layer}}$) in the lowest 25 % of the range of inner layer DR's and the other size has an ILDR in the upper 25 % of the range.

S5.2.2 Initiate testing of one specimen of each of the sizes determined in S5.2.1 at the highest temperature/pressure (for example, 115°C/60 psi) condition used for the solid wall. This is condition ML1.

S5.2.3 Initiate testing of one specimen at the same temperature, but a higher stress level (for example, 115°C/80 psi). This is condition ML2. The specimen shall be the thinnest inner-layer product of the two sizes.

S5.2.4 Initiate testing of one specimen at the same stress level and next lowest temperature used for the original solid-wall testing (for example, 105°C/80 psi). This is condition ML3. The specimen shall be the heavier inner-layer wall thickness product of the two sizes.

S5.2.5 Calculate the expected fail times (EFT) for each size being tested at each condition in accordance with S5.3.

S5.2.6 Two methods of evaluation are available for the multi-layer finished product testing. The pipe specimens tested at conditions ML1, ML2 and ML3 shall meet the requirements of S5.2.6.1 or S5.2.6.2.

S5.2.6.1 For this method, continue testing each specimen to 150 % of EFT for each condition. Failure of any specimen prior to 150 % of EFT shall constitute a failure of this test.

S5.2.6.2 For this alternate method, continue the testing of each specimen until each specimen has the following times are achieved:

- (1) ML1 – 100 % of EFT
- (2) ML2 – 150 % of EFT
- (3) ML3 – 50 % of EFT

Failure of any specimens prior to the EFT at each test condition shall constitute a failure of this test.

S5.2.6.2.1 Examine each of the ML3 specimens to determine the amount of crack propagation through the inner wall at the location with the heaviest signs of cracking. Cracks propagating completely through the inner wall in these specimens shall be considered a failure of this test.

S5.2.6.2.2 To aid in determination of the crack propagation at the inner wall, the ML3 (50 % fail time, heaviest wall) specimen is cut longitudinally and examined microscopically. Regions exhibiting the most severe cracking and oxidation of the inner layer are then sectioned laterally. This lateral cut is examined microscopically to determine if brittle cracks have reached the aluminum layer. If the inner layer is sufficiently embrittled such that the specimen cannot be sectioned for examination, it shall be considered a failure of this test.

S5.3 *Calculation of Expected Fail Times for Multi-layer Construction*—The expected fail times used for testing the multi-layer products shall be determined in accordance with S5.3.1–S5.3.3.

S5.3.1 *Known Quantities and Symbols*—The following values must be known for each multi-layer construction in order to complete the calculations:

- Tubing OD, mm
- Outer PEX layer thickness, t_{opex} , mm
- Aluminum thickness, t_{AL} , mm
- Inner PEX layer thickness, t_{ipex} , mm
- PEX tensile modulus, E_{pex} , MPa
- Aluminum tensile modulus, E_{AL} , MPa

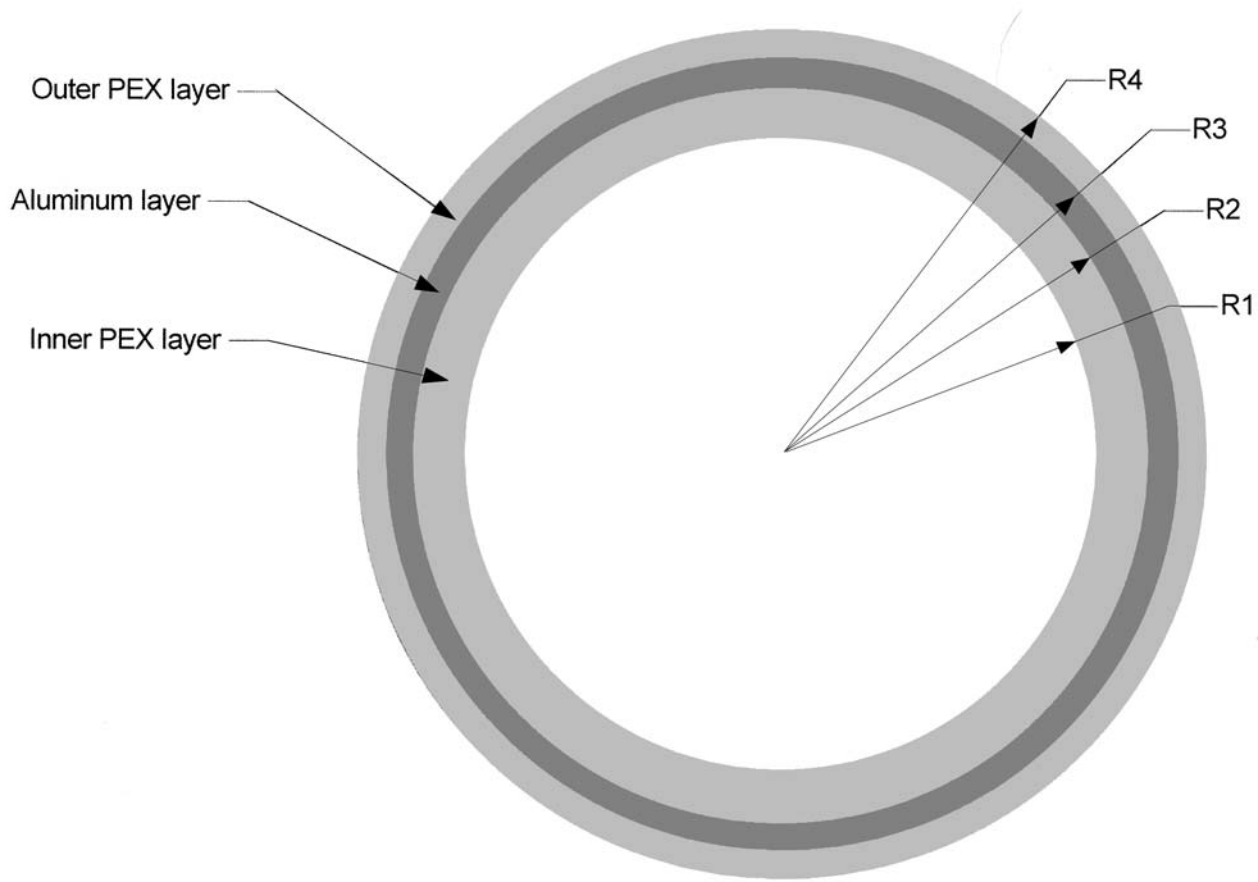


FIG. S1 Multi-layer Construction and Definition of Different Radii

Adhesive layer thickness, mm

Internal pressure, P, MPa

Temperature, T, K

Coefficients for stress-rupture equation of solid PEX, C1, C2, C4

S5.3.2 *Preliminary Calculations*—Determine the various radii and dimension ratio as follows:

$$R4 = (\text{tubing OD}) / 2$$

$R3 = R4 - (\text{outer PEX layer thickness} + \text{outer adhesive thickness})$

$$R2 = R3 - \text{aluminum layer thickness}$$

$R1 = R2 - (\text{inner PEX layer thickness} + \text{inner adhesive thickness})$

Dimension ratio of aluminum, $DR_{AL} = 2 \cdot R3 / t_{AL}$

S5.3.3 *Procedure*—Determine the estimated fail time of the inner layer in accordance with S5.3.3.1–S5.3.3.5.

S5.3.3.1 Calculate the circumferential strain in the aluminum layer based on internal pressure. Assume that the stress is sufficiently low that the aluminum behaves linearly.

Hoop stress in aluminum layer:

$$\sigma_{AL} = \frac{P}{2} (DR_{AL} - 1) \quad (1)$$

Circumferential strain in aluminum layer:

$$\epsilon_{AL} = \frac{\sigma_{AL}}{E_{AL}} \quad (2)$$

S5.3.3.2 Assume the strain in the inner PEX layer is the same as the strain in the aluminum layer. Use this strain to calculate stress in the PEX layer.

NOTE S1—This assumes small, linear strains in the PEX. This will be a reasonable assumption with the aluminum reinforcing layer, provided the aluminum is still in the linear region.

Stress at inner PEX layer:

$$\sigma_{PEX} = (\epsilon_{AL}) (E_{PEX}) \quad (3)$$

S5.3.3.3 Calculate the estimated fail time based on this stress and the temperature of interest (that is, test temperature or end-use temperature).

Fail time of inner layer:

$$\text{Log}(f) = C1 + \frac{C2}{T} + \frac{C4}{T} \cdot \text{Log}(\sigma_{PEX}) \quad (4)$$

S5.3.3.4 Adjust the expected fail time based on the ratio of the inner layer thickness to the original solid-wall test sample thickness.

Adjusted inner layer fail time:

$$f' = f \frac{(\text{inner layer thickness})}{(\text{solid} - \text{wall thickness})} \quad (5)$$

S5.3.3.5 This adjusted inner layer fail time is the expected fail time (EFT) for use in S5.2, Application to Multi-layer Construction.

S5.3.3.6 Calculate the 95 % lower confidence limit for the multi-layer product at an internal pressure of 5.5 MPa (80 psig) and temperature of 60°C (140°F) using Eq 6 and the pipe dimensions that result in the maximum inner layer hoop stress within the product range. Designate this result as LCL_{60} . Repeat this calculation using an internal pressure of 5.5 MPa (80 psig) and temperature of 23°C (73°F). Designate this as LCL_{23} .

95 % LCL of the expected time to failure for multi-layer product at 60°C (see ISO 9080 or a statistics text for details):

$$\text{Log}(f) = C1 + \frac{C2}{T} + \frac{C4}{T} \cdot \text{Log}(\sigma_{80}) - (t) (s) \left[\frac{1}{n} + X_o^T (X^T X)^{-1} X_o \right]^{1/2} \quad (6)$$

S5.3.3.7 Calculate the Miner's Rule extrapolated time using the LCL values (LCL_{60} and LCL_{23}) from S5.3.3.6 in Eq 7. Eq 7 assumes the product is operated at 23°C for 75 % of the time, and 60°C for 25 % of the time, both at an internal pressure of 80 psig.

Miner's Rule calculation for extrapolated time to failure:

$$\text{Extrapolated time (h)} = \frac{100}{\frac{25}{LCL_{60}} + \frac{75}{LCL_{23}}} \quad (7)$$

ANNEXES

(Mandatory Information)

A1. CONNECTORS

A1.1 Connectors shall be made from brass or any other material found to be suitable for the service conditions.

A1.2 The connectors shall be designed so that a seal is effected on the internal wall surface of the pipe so that the medium contained in the pipe is precluded from coming into

contact with the cut end of the pipe.

A1.3 Connectors not made from brass shall be capable of meeting the short term pipe test requirements listed in 6.5 and 6.6 of this specification and the long-term hydrostatic capabilities of the pipe at elevated temperatures listed in Appendix X1.

A2. PERFORMANCE REQUIREMENTS OF CONNECTORS

A2.1 *General*—All performance testing of connectors shall be performed on assemblies of connectors and PEX/AL/PEX pipe meeting the requirements of this specification. Assembly of test specimens shall be in accordance with Appendix X3. Use separate sets of assemblies for each performance test requirement.

NOTE A2.1—Fittings manufactured in compliance with Specification F 1974 meet all of the performance requirements provided in this Annex.

A2.2 *Hydrostatic Burst*—Assemblies shall meet the minimum hydrostatic burst requirements shown in Table A2.1 when tested in accordance with 9.5, except that the test temperature shall be 180°F (82.2°C).

A2.3 *Hydrostatic Sustained Pressure Strength*—Pipe and

connector assemblies shall not separate or leak when tested in accordance with A2.6.2.

A2.4 *Thermocycling*—Assemblies shall not leak or separate when thermocycled 1000 cycles between the temperatures of 60°F (15.6°C) and 180°F (82.2°C) in accordance with A2.6.3.

A2.5 *Excessive Temperature-Pressure Capability*:

A2.5.1 *General*—In the event of a water heating system malfunction assemblies shall have adequate strength to accommodate short-term conditions, 48 h or 210 ± 4°F (99 ± 2°C) and 150 psi (1034 kPa) until repairs can be made.

A2.5.2 *Excessive Temperature Hydrostatic Sustained Pressure*—Assemblies shall not leak or separate when tested in accordance with A2.6.4.

A2.6 *Test Methods*:

A2.6.1 Sampling and Conditioning shall be done in accordance with Section 8.

A2.6.2 *Hydrostatic Sustained Pressure*:

A2.6.2.1 Perform the test on at least six assemblies in accordance with Test Method D 1598, except for the following:

- (1) The test temperature shall be at 180 ± 4°F (82.2 ± 2°C),
- (2) Test pressure shall be 320 psi (2 205 kPa),
- (3) The external test environment shall be air or water, and
- (4) The specimens shall be filled with water at a temperature of at least 120°F (49°C).

TABLE A2.1 Minimum Hydrostatic Burst Strength Requirements for Connector and PEX/AL/PEX Pipe Assemblies

Nominal Pipe Size, mm (in.)		Minimum Burst Pressures	
		psi at 180°F	kPa at 82.2°C
1216	(1/2)	580	(4000)
1620	(5/8)	550	(3800)
2025	(3/4)	465	(3200)
2532	(1)	465	(3200)
3240	(1 1/4)	362	(2500)
4150	(1 1/2)	333	(2300)
5163	(2)	295	(2000)
6075	(2 1/2)	295	(2000)

A2.6.2.2 Leakage or separation at any joint tested at less than 1000 h at the sustained pressure shall constitute failure in this test.

A2.6.3 Thermocycling:

A2.6.3.1 *Summary of Test Method*—This test method describes a pass-fail test for thermally cycling assemblies comprised of insert connector and pipe over a critical temperature range for a selected number of cycles while subjected to an internal pressure. The test provides a measure of resistance to failure due to the combined effects of differential thermal expansion and creep of connections intended for use up to and including 180°F (82.2°C).

A2.6.3.2 *Apparatus*—A compressed air or nitrogen pressure source capable of maintaining an internal pressure of 100 ± 10 psi (690 ± 69 kPa) on the specimens is required. A dip test apparatus capable of automatically immersing test samples at prescribed intervals in temperature controlled water baths capable of providing continuous water temperatures of $60 \pm 4^\circ\text{F}$ ($15.6 \pm 2^\circ\text{C}$) and $180 \pm 4^\circ\text{F}$ ($82.2 \pm 2^\circ\text{C}$) is required.

A2.6.3.3 *Specimen Preparation*—Six assemblies of the type of connector to be tested shall be prepared. The connectors with suitable lengths of pipe meeting the requirements of the applicable standard shall be assembled and attached to a common manifold. Assemble strictly according to the instructions of the connector manufacturer. Close the specimen assembly with any suitable end closures that allow “free end” mounting and will not leak under the thermocycling conditions, and connect the specimen assembly to the pressure source.

A2.6.3.4 *Procedure*—Correction to correspond with 100 ± 10 psi (690 ± 69 kPa), immerse in $60 \pm 4^\circ\text{F}$ ($15.6 \pm 2^\circ\text{C}$) water, and check for leaks. Eliminate all leaks before the thermocycling test is started. With the specimen assembly pressurized to 100 ± 10 psi (690 ± 69 kPa), thermally cycle it between $60 \pm 4^\circ\text{F}$ ($15.6 \pm 2^\circ\text{C}$) and $180 \pm 4^\circ\text{F}$ ($82.2 \pm 2^\circ\text{C}$) by means of immersion in water using the following test cycle (see **Note A2.2**):

Water immersion at 180°F (82.2°C)	2 min minimum
Air immersion at ambient	2 min maximum
Water immersion at 60°F (15.6°C)	2 min minimum
Air immersion at ambient	2 min maximum

NOTE A2.2—If the test must be interrupted before completion, samples are to be kept at room temperature until the test is restarted.

(1) Upon completion of 1000 cycles, immerse the specimen assembly again in 60°F ($15.6 \pm 2^\circ\text{C}$) water, and check for

leaks. Any evidence of leakage at the connectors or separation of the connectors from the pipe constitutes failure.

(2) If no failures are evident, the specimen assembly shall immediately be tested for joint integrity (hydrostatic burst) at 73°F (23°C) in accordance with Test Method **D 1599**. Leakage or separation during the hydrostatic burst test of any of the joints in the assembly at less than the pressure shown in **Table A2.1** shall constitute failure of this test.

A2.6.3.5 *Interpretation of Results*—Failure of any one of six specimens in the assembly shall constitute failure of this test.

A2.6.4 Excessive Temperature and Pressure Capability:

A2.6.4.1 Test six assemblies in accordance with Test Method **D 1598**, except the following:

- (1) The test temperature shall be $210 \pm 4^\circ\text{F}$ ($99 \pm 2^\circ\text{C}$),
- (2) The test pressure shall be 150 psi (1 034 kPa),
- (3) The external test environment shall be air,
- (4) The specimens shall be filled with water at a temperature of at least 120°F (49°C).

A2.6.4.2 Leakage or separation at any joint tested at less than 720 h at the test pressure shall constitute failure in this test.

A2.7 Product Marking of Connectors:

A2.7.1 *Quality Assurance*—When the connector or connector packing is marked with the ASTM Designation F 1281, the manufacturer affirms that the product was manufactured, inspected, sampled, and tested in accordance with this specification and has been found to meet the requirements of this specification.

A2.7.2 *Quality of Marking*—The marking shall be applied to the connectors in such a manner that it remains legible after installation and inspection.

A2.7.3 Content of Marking:

A2.7.3.1 Marking on connectors shall include:

(1) Manufacturer’s name or trademark, or some other identifying mark, and

(2) F 1281 or F 1281/2, the standard designation.

A2.7.3.2 Marking on packaging shall include:

(1) Manufacturer’s name,

(2) Connector size, and

(3) “ASTM F 1281”.

A2.7.3.3 Marking on crimp rings shall include the code letters, PAP.

APPENDIXES

(Nonmandatory Information)

X1. PRESSURE RATING

X1.1 The hydrostatic design basis-pressures for water recommended by the Plastic Pipe Institute are used to pressure rate the PEX-AL-PEX composite pipe covered by this specification. These design basis-pressures are 2.76 MPa (400 psi) at 23°C (73.4°F), 2.21 MPa (320 psi) at 60°C (140°F) and 1.72 MPa (250 psi) at 83°C (180°F). These hydrostatic design basis-pressures apply only to pipe meeting all of the require-

ments of this specification.

X1.2 The PEX-AL-PEX composite pipe meeting the requirements of this specification shall be pressure rated for maximum water pressures of 1.38 MPa (200 psi) at 23°C (73.4°F), 1.10 MPa (160 psi) at 60°C (140°F) or 0.86 MPa (125 psi) at 83°C (180°F), or a combination thereof.

X2. STORAGE

X2.1 *Outside Storage*—Pipe should be stored on a flat surface and supported in a manner that will prevent distortion.

X3. JOINING

X3.1 Cut the pipe square to the proper length.

X3.2 Select the proper size tool (if required) for pipe preparation/joining. Only use tools specific to the design of the connector system.

X3.3 Assemble and complete the joint in accordance with the manufacturer's instructions specific to the type of connectors being used.

ASTM International takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, at the address shown below.

This standard is copyrighted by ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States. Individual reprints (single or multiple copies) of this standard may be obtained by contacting ASTM at the above address or at 610-832-9585 (phone), 610-832-9555 (fax), or service@astm.org (e-mail); or through the ASTM website (www.astm.org).