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Crosslinked Polyethylene (PEX) Pipe & Tubing

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Foreword

This report was developed and published with the technical help and financial support of the members of the Plastics Pipe Institute (PPI). These members are committed to developing and improving quality products by assisting independent standards and user organizations in the development of standards, and also by developing design aids and reports to help engineers, code officials, specifying groups, contractors and users.

The purpose of this technical note is to provide general information on crosslinked polyethylene (PEX) pipe and tubing, how it is manufactured and in what applications it can be used.

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The Plastics Pipe Institute Inc.

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CROSSLINKED POLYETHYLENE (PEX)
PIPE & TUBING

1.0 Introduction

The successful use of crosslinked polyethylene (PEX) systems throughout the world, along with the capabilities of PEX piping in cold- and hot-water environments, have generated significant interest and growth in the usage in these materials across North America. To answer common questions about PEX materials from installers, designers, builders and specifiers, as well as the public, this technical note provides an overview of PEX properties and capabilities, the applications and benefits of PEX, and the technical requirements for PEX systems. Several product standards are listed as references.

2.0 What is PEX?

PEX is the acronym for Crosslinked Polyethylene.

2.1 Formal Definition – Crosslinked Polyethylene is a polyethylene material which has undergone a change in molecular structure using a chemical or a physical process whereby the polymer chains are chemically linked. Crosslinking of polyethylene into PEX for pipes results in improved properties such as elevated temperature strength and performance, chemical resistance, and resistance to slow crack growth.

2.2 Explanation – PEX is a modified polyethylene material, typically high-density polyethylene (HDPE), which has undergone a change in the molecular structure using a chemical or a physical process whereby the polymer chains are permanently linked to each other. This crosslinking of the polymer chains results in improved performance properties such as elevated temperature strength, chemical resistance, environmental stress crack resistance (ESCR), resistance to slow crack growth (SCG), toughness, and abrasion resistance. Crosslinking also makes PEX a “semi-thermoset” polymer, providing excellent long-term stability.

3.0 How does crosslinking improve properties from HDPE?

Below is a table summarizing the property changes from HDPE to PEX materials in general:

Table 1

Property	Change from HDPE to PEX	Benefit
Tensile Yield Strength @ 73.4°F (23°C) Tensile Yield Strength @ 180°F (82°C)	Typically Unchanged Typically Increases	PEX is suitable for both low- and elevated-temperature applications
Elongation at Break	Unchanged or Increases	Improved flexibility to withstand installation stresses while resisting tensile deformation
Environmental Stress Crack Resistance	Increases	Greater resistance to environmental hazards. Improved toughness and abrasion resistance.
Resistance to Slow Crack Growth	Increases	Greater resistance to environmental hazards such as scratches. Improved toughness and abrasion resistance.
Creep Resistance	Increases	Improved stability over long-term pressurization and loads. The traditional HDPE stress curve "knee-point" is typically eliminated.
Hydrostatic Design Basis (HDB): HDB @ 73.4°F (23°C) HDB @ 180°F (82°C)	 Typically Unchanged Increases	HDB is an evaluation of the long-term hoop strength of the material, and is used to develop its pressure ratings. PEX is suitable for both low- and elevated-temperature applications
Hydrocarbon Permeation	Unchanged	Similar performance
Chemical Resistance *	Typically Increases	Similar or improved performance
* *The chemical resistance of thermoplastics is complex and is generally a function of the polymer's resistance to applied load, temperature and environment*		

4.0 Elevated temperature capabilities

In general, 140°F (60°C) is the typical maximum service temperature for thermoplastic HDPE pressure pipe applications. With PEX, however, the in-service temperature can be raised to at least 180°F (82°C) and sometimes as high as 200°F (93°C), depending on the starting density, degree of crosslinking and type of crosslinking. PEX pipes are also tested to ensure that short-term exposure to a temperature of 210°F (99°C) is also tolerated.

5.0 How is PE Crosslinked into PEX?

Polyethylene can be crosslinked using several technologies or methods. All methods create links or bonds between the single chains of PE to form a dense molecular network through chemical reactions. The number of links between the polyethylene molecules determines the crosslink density, and is an important factor in determining the physical properties of the material.

The three most common methods of crosslinking polyethylene are as follows:

5.1 Peroxide – This method employs organic peroxides that, when heated, generate reactive free radicals that splice PE chains together during extrusion. This is sometimes referred to as the *PEX-a Process*.

5.2 Silane – This method involves grafting a reactive silane molecule to the backbone of the polyethylene. This is sometimes referred to as the *PEX-b Process*.

5.3 Electron beam – This method involves subjecting the extruded PE pipe to a dose of high-energy electrons. This is sometimes referred to as the *PEX-c Process*.

NOTE: The letter designations are not related to any type of performance rating system. PEX pipe produced by each of the three methods must meet the same technical requirements as specified in the relevant PEX standards.

Although the three methods of crosslinking produce slightly different pipe characteristics, all three are commonly used to manufacture approved PEX products. As required in any manufacturing process, procedures for each technology must be established and followed with good quality control checks in place to produce quality products.

6.0 What are the typical configurations of PEX tubing or piping systems?

NOTE: In this document, “tubing” refers to PEX products where the actual OD is 1/8 inch larger than the nominal size, the same as copper tube sizes (CTS) – see ASTM F876. “Pipe” refers to PEX products where the actual OD matches the nominal size – see ASTM F2788. In both cases, specified tolerances apply, as per relevant standards.

6.1 PEX tubing – comes in nominal sizes ranging from 1/4 to 3 in. CTS. The wall thickness is based upon standard dimensional ratio (SDR) 9 values, which yield standard hydrostatic pressure ratings of 160 psi at 73.4°F, and 100 psi at 180°F. Additionally, some PEX tubing products are rated to 80 psi at 200°F. Consult the specific PEX manufacturer’s literature and listings for appropriate pressure ratings. PEX tubing is sold in coils and straight lengths.

A wide selection of fittings, constructed of metal or polymer, is available for PEX tubing. PEX fittings are also subject to specific product specifications and standardized test requirements. Some PEX fittings shall only be joined to certain types of PEX tubing, as recommended by the tubing manufacturers. This will be indicated with markings on the tubing.

6.2 PEX pipe – comes in nominal sizes ranging from 16 to 1000 mm outside diameter. Several standard dimensional ratio (SDR) values apply to PEX pipe, controlling the wall thickness.

6.3 Coatings and barriers – Some PEX tubing and pipes are available with specific coatings or barriers for specific purposes such as oxygen diffusion, UV resistance, color-coding, etc. The specific performance of these coatings or barriers should be discussed with the PEX manufacturer to ensure the correct PEX material is used for the application.

NOTE: Consult model, national and local codes (or "applicable codes") and the authority having jurisdiction (AHJ) when selecting the type of PEX pipe or tubing and components for specific applications. Also, consult the PEX manufacturer for specific approvals, recommendations and limitations.

7.0 What are the applications for PEX?

PEX is typically used in the following applications:

- Potable cold- and hot-water distribution systems, both residential and commercial
- Residential fire protection systems
- Hydronic radiant heating and cooling, using warm or chilled fluids
- Outdoor snow and ice melting
- Outdoor turf conditioning
- Ice surface piping
- Hot-water distribution piping
- Hot-water baseboard piping
- Warm- and hot-water radiator connection piping
- Potable water service pipes
- Natural gas distribution
- Geothermal ground loop heat exchangers
- Chilled water piping
- Specialized industrial and mining applications

NOTE: PEX is typically *not* used for refrigerant line piping or medical gas applications.

PEX is a unique material that provides many opportunities for new applications. Please discuss your application with any PEX manufacturer to determine if PEX is the material of choice for the application.

8.0 What are the advantages of PEX systems?

For potable water applications, PEX systems offer the following advantages over competing materials as documented in the ***"Design Guide for Residential PEX Water Supply Plumbing Systems",*** published by PPI, PPFA and the NAHB Research Center (please refer to the "Guide" for additional details):

- Speed and ease of installation
- Cost effectiveness
- Energy efficiency
- Elevated temperature capability
- Long-term hydrostatic strength stability
- Electrolysis resistance
- Corrosion resistance
- Tuberculation resistance
- Erosion resistance
- Durability and toughness
- Flexibility, even at cold temperatures
- Resistance to chlorine and chloramines
- Resistance to most chemicals found on construction sites
- Noise and water hammer resistance (pressure surge absorption)
- No solvent or chemical joining required
- Resistance to freeze damage

For other applications, these same advantages apply for PEX systems.

Additional distinct advantages may be found in other applications, depending on the traditional material used as the basis for comparison.

9.0 Code acceptance of PEX Systems

PEX plumbing systems are recognized by all major building codes, including (but not limited to) the: *International Residential Code*, *International Plumbing Code*, *National Standard Plumbing Code*, *Uniform Plumbing Code* and the *National Plumbing Code of Canada*.

PEX heating systems are recognized by the *Uniform Mechanical Code* and by CSA B214, *Installation Code for Hydronic Heating Systems* (Canada).

PEX systems are also recognized by certain codes for water service line, chilled water piping, geothermal heat exchangers and more, with specific requirements. An example of other codes includes ASME B31.9.

NOTE: Consult applicable codes and the authority having jurisdiction (AHJ) when selecting the type of PEX pipe or tubing and components for specific applications. Also consult the PEX manufacturer for specific approvals, recommendations and limitation.

10.0 What are the technical qualification requirements for PEX?

In order to qualify a PEX tubing or piping product for commercial market use, a manufacturer's product and piping system must be evaluated and approved to one or more of the following requirements, depending on application/s:

- ASTM F876 - *Standard Specification for Crosslinked Polyethylene (PEX) Tubing*
- ASTM F877 - Standard Specification for Crosslinked Polyethylene (PEX) Plastic Hot- and Cold-Water Distribution Systems
- ASTM F2023 – Standard Test Method for Evaluating the Oxidative Resistance of Crosslinked Polyethylene (PEX) Tubing and Systems to Chlorinated Hot Water
- ASTM F2657 - Standard Test Method for Outdoor Weathering Exposure of Crosslinked Polyethylene (PEX) Tubing
- ASTM F2788 – Standard Specification for Metric-sized Crosslinked Polyethylene (PEX) Pipe
- ASTM F2818 – Standard Specification for Specification for Crosslinked Polyethylene (PEX) Material Gas Pressure Pipe and Tubing
- ASTM F2829 - Standard Specification for Metric-Sized Crosslinked Polyethylene (PEX) Pipe Systems
- AWWA C904 Cross-Linked Polyethylene (PEX) Pressure Pipe, ½ inch (12 mm) Through 3 inch (76 mm), for Water Service.
- CSA International B137.5 - Crosslinked Polyethylene Tubing Systems for Pressure Applications.
- PPI 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.
- NSF/ANSI Standard 14 – Plastics Piping System Components and Related Materials (for both potable water and radiant floor heating applications).
- NSF/ANSI Standard 61 - Drinking Water System Components - Health Effects (for potable water applications only).

The text in sections 10.1 through 10.12 explains these referenced technical standards using the abstracts and summaries of those standards as published by ASTM, AWWA, CSA, NSF and PPI, respectively, with permissions as shown.

10.1 ASTM F876

This specification covers crosslinked polyethylene (PEX) tubing that is outside diameter controlled, made in standard thermoplastic tubing dimension ratios, and pressure rated for water at three temperatures. This specification covers one PEX tubing material in one standard dimension ratio and having pressure ratings for water of three temperatures. The pressure ratings decrease as the

temperature is increased. PEX tubing shall be made from polyethylene compounds which have been crosslinked by peroxides, Azo compounds, or silane compounds in extrusion, or by electron beam after extrusion, or by other means such that the tubing meets the performance requirements. The following tests shall be performed: dimensions and tolerances; density; sustained pressure test; burst pressure; environmental stress cracking test; degree of crosslinking; stabilizer functionality; and oxidative stability in potable chlorinated water applications.

Extracted, with permission, from ASTM F876 - *Standard Specification for Crosslinked Polyethylene (PEX) Tubing, copyright ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428. A copy of the complete standard may be purchased from ASTM International, www.astm.org*

10.2 ASTM F877

This specification covers requirements, test methods, and marking requirements for system components when tested with nominal SDR9 crosslinked polyethylene tubing as a system. Systems are intended for 100 psi (0.69 MPa) water service up to and including a maximum working temperature of 180°F (82°C). Requirements and test methods are included for materials, workmanship, dimensions and tolerances, burst pressure, sustained pressure, excessive temperature and pressure, and thermo-cycling tests. The components covered by this specification are intended for use in residential and commercial, hot and cold, potable water distribution systems or other applications such as municipal water service lines, radiant panel heating systems, hydronic baseboard heating systems, snow and ice melting systems, and building services pipe.

Extracted, with permission, from ASTM F877 - Standard Specification for Crosslinked Polyethylene (PEX) Plastic Hot- and Cold-Water Distribution Systems, copyright ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428. A copy of the complete standard may be purchased from ASTM International, www.astm.org

10.3 ASTM F2023

This test method describes the general requirements for evaluating the long-term oxidative resistance of cross-linked polyethylene (PEX) tubing produced in accordance with ASTM F876 or PEX tubing/fitting systems produced in accordance with ASTM F877 by exposure to hot, chlorinated water used in hot- and cold-water distribution systems. This test method is applicable to PEX tubing and systems used for transport of potable water containing free-chlorine for disinfecting purposes. The oxidizing potential of the test-fluid specified in this test method exceeds that typically found in potable water systems across the United States.

NOTE: Other known disinfecting systems (chlorine dioxide, ozone, and chloramines) are currently used for protection of potable water; however, free-chlorine is by far the most common system in use today. Chloramines have been tested in comparison to free-chlorine utilizing ASTM F2023 by PPI and found to be significantly less aggressive to PEX piping. Please refer to the PPI Technical Report Statement A on the PPI website (www.plasticpipe.org) for more details. Disinfecting systems other than chlorine and chloramines have not been evaluated by this method.

Extracted, with permission, from ASTM F2023 – Standard Test Method for Evaluating the Oxidative Resistance of Crosslinked Polyethylene (PEX) Tubing and Systems to Chlorinated Hot Water, copyright ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428. A copy of the complete standard may be purchased from ASTM International, www.astm.org

10.4 ASTM F2657

This test method describes the procedure for exposing crosslinked polyethylene (PEX) tubing produced in accordance with Specification F876 to natural (sunlight) ultraviolet (UV) radiation and evaluating the effects of the exposure. This test method outlines the requirements for specimen size and preparation, exposure orientation, minimum UV exposure energy, post exposure testing and reporting.

Extracted, with permission, from ASTM F2657 - Standard Test Method for Outdoor Weathering Exposure of Crosslinked Polyethylene (PEX) Tubing, copyright ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428. A copy of the complete standard may be purchased from ASTM International, www.astm.org

10.5 ASTM F2788

This specification covers metric-sized crosslinked polyethylene (PEX) pipe that is outside diameter controlled, made in nominal pipe dimension ratios, and pressure rated for water at three temperatures (see Appendix X1). Included are requirements and test methods for material, workmanship, dimensions, burst pressure, hydrostatic sustained pressure, excessive temperature-pressure, environmental stress cracking, stabilizer functionality, bent-pipe hydrostatic pressure, oxidative stability in potable chlorinated water, and degree of crosslinking. Requirements for pipe markings are also given. The pipe covered by this specification is intended for buried pressure piping applications (such as, industrial and general-purpose pipelines, potable water pipelines, fire – extinguishing pipelines). This specification also includes carbon black requirements for PEX pipe used for aboveground pressure piping applications.

Extracted, with permission, from ASTM F2788 – Standard Specification for Metric-sized Crosslinked Polyethylene (PEX) Pipe, copyright ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428. A copy of the complete standard may be purchased from ASTM International, www.astm.org.

10.6 ASTM F2818

This specification covers requirements and test methods for material dimensions and tolerances, hydrostatic burst strength, chemical resistance, and impact resistance of PEX pipe and tubing for use in fuel gas mains and services for direct burial applications.

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10.7 ASTM F2829

This specification covers performance requirements, test methods, and marking requirements for metric-sized system components (electrofusion and mechanical fittings) when joined with metric-sized PEX pipe (Specification F2788) as a system, intended for use up to and including a maximum working temperature of 200°F (93°C). The following performance requirements are described for the fittings – 68°F (20°C) hydrostatic strength, 176°F (80°C) hydrostatic strength, short-term internal pressure resistance, resistance to tensile loads, cohesive resistance for electrofusion fittings at both the minimum and maximum recommended temperatures, impact resistance for saddle fittings, and leak tightness and pull out tests for mechanical fittings. The metric-sized components covered by this specification are intended for the above-ground and buried pressure piping applications, such as industrial & general-purpose pipelines, potable water pipelines, and fire–extinguishing pipelines.

Extracted, with permission, from ASTM F2829 - Standard Specification for Metric-Sized Crosslinked Polyethylene (PEX) Pipe Systems, copyright ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428. A copy of the complete standard may be purchased from ASTM International, www.astm.org

10.8 AWWA C904

This standard describes Crosslinked Polyethylene (PEX) pressure pipe made from material having a standard PEX material designation code of PEX 1006 in ASTM F876 for use as underground water service lines in sizes ½ in. (12mm) through 3 in. (76mm) that conform to a standard dimension ratio of SDR9. The purpose of this standard is to provide the requirements for materials, design, testing, inspection, and shipping of PEX pipe for use as service lines in the construction of underground water distribution systems. This standard can be referenced for purchasing and receiving PEX pressure pipe and as a guide for manufacturing PEX pressure pipe.

10.9 CSA B137.5

This Standard specifies requirements for crosslinked polyethylene (PEX) tubing systems, comprised of tubing and fittings. Tubing covered by this Standard is made in Standard Dimensional Ratio 9 (SDR 9). Systems are pressure rated at three temperatures: 1105 kPa at 23°C, 690 kPa at 82°C, and 550 kPa at 93°C, with a maximum working pressure of 690 kPa at 82°C. Systems are intended for use in potable water distribution systems or other applications, including municipal water service lines, reclaimed water distribution, radiant panel heating and cooling systems, hydronic baseboard heating systems, snow and ice melting heating systems, building services piping, compressed air distribution, and ground source geothermal systems, provided that the PEX tubing systems covered herein comply with the applicable code requirements. Residential and commercial systems are included.

10.10 PPI TR-3

This technical report presents the policies and procedures used by the HSB (Hydrostatic Stress Board) of the PPI (Plastics Pipe Institute) to develop recommendations of estimated long-term hydrostatic strength for commercial thermoplastic piping materials. Recommendations are published in PPI technical report TR-4, “PPI Listing of Hydrostatic Design Basis, and Hydrostatic Design Stress (HDS), Strength Design Basis (SDB), Pressure Design Basis (PDB) and Minimum Required Strength (MRS) Ratings for Thermoplastic Piping Materials or Pipe”.

Listings are developed from data submitted to the HSB by the manufacturer. These data are obtained according to the basic method outlined in ASTM D1598, “Standard Test Method for Time-to-Failure of Plastic Pipe Under Constant Internal Pressure.” The general method used to evaluate the data is described in ASTM D2837, “Standard Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials,” with additional requirements as specified in PPI TR-3.

TR-3 and TR-4 also provide the recommended pipe material designation codes for PEX materials. An example of this pipe material designation code is as follows:

PEX 1006 is a crosslinked polyethylene (the PEX abbreviation is in accordance with ASTM D1600) which has a 630 psi maximum recommended HDS (0.5 design factor) at 73°F (23°C).

Unlike thermoplastic PE material designation codes, the first two digits of the PEX material designation code cannot be used to describe its short-term properties.

- **The first digit** of the PEX material designation code is for chlorine resistance tested in accordance with ASTM F2023.
  - A digit “1” indicates the PEX tubing has been tested and meets the F876 requirement for minimum chlorine resistance at the end use condition of 25% at 140°F (60°C) and 75% at 73.4°F (23°C).
  - A digit “3” indicates the PEX tubing has been tested and meets the F876 requirement for minimum chlorine resistance at the end use condition of 50% at 140°F (60°C) and 50% at 73.4°F (23°C).
  - A digit “5” indicates the PEX tubing has been tested and meets the F876 requirement for minimum chlorine resistance at the end use condition of 100% at 140°F (60°C).
  - A digit “0” indicates it does not meet this requirement or it has not been tested.
- **The second digit** of the PEX material designation code is used to indicate the level of UV resistance for the PEX material when tested in accordance with ASTM F2657.
  - A digit “1” indicates the PEX tubing has been tested and meets the F876 requirement for minimum UV resistance of 1 month.
  - A digit “2” indicates the PEX tubing has been tested and meets the F876 requirement for minimum UV resistance of 3 months.
  - A digit “3” indicates the PEX tubing has been tested and meets the F876 requirement for minimum UV resistance of 6 months.
  - A digit “0” indicates it does not meet any minimum UV resistance requirement or it has not been tested.
- **The last two digits** of the PEX material designation code represent the PPI recommended HDS (0.5 design factor) at 73.4°F (23°C) divided by one hundred.

10.11 NSF/ANSI Standard 14

This standard establishes minimum physical, performance, quality assurance, marking, and record keeping requirements for plastic piping components and related materials.

10.12 NSF/ANSI Standard 61

This standard is intended to cover specific materials or products that come into contact with drinking water, drinking water treatment chemicals, or both. The primary focus of the standard is on contaminants or impurities imparted indirectly to drinking water.

PEX tubing used in the transport of potable water must be marked “POTABLE” or have the seal of a lab that has evaluated the tubing against the requirements of NSF/ANSI Standard 61.

11.0 PEX Fittings

In addition to the above standards, requirements and test methods for PEX tubing and piping, there are also specific product standards for PEX fitting systems. These product standards include, but are not limited to:

- ASTM F877 *Standard Specification for Crosslinked Polyethylene (PEX) Hot- and Cold-Water Distribution Systems*
- ASTM F1055 *Standard Specification for Electrofusion Type Polyethylene Fittings for Outside Diameter Controlled Polyethylene and Crosslinked Polyethylene (PEX) Pipe and Tubing*
- ASTM F1807 *Standard Specification for Metal Insert Fittings Utilizing a Copper Crimp Ring for SDR9 Crosslinked Polyethylene (PEX) Tubing and SDR9 Polyethylene of Raised Temperature (PE-RT) Tubing*
- ASTM F1865 *Standard Specification for Mechanical Cold Expansion Insert Fitting With Compression Sleeve for Crosslinked Polyethylene (PEX) Tubing*
- *ASTM F1960 Standard Specification for Cold Expansion Fittings with PEX Reinforcing Rings for Use with Crosslinked Polyethylene (PEX) Tubing*
- ASTM F2080 *Standard Specification for Cold-Expansion Fittings With Metal Compression-Sleeves for Crosslinked Polyethylene (PEX) Pipe*
- ASTM F2159 *Standard Specification for Plastic Insert Fittings Utilizing a Copper Crimp Ring for SDR9 Crosslinked Polyethylene (PEX) Tubing and SDR9 Polyethylene of Raised Temperature (PE-RT) Tubing*
- ASTM F2434 *Standard Specification for Metal Insert Fittings Utilizing a Copper Crimp Ring for SDR9 Cross-linked Polyethylene (PEX) Tubing and SDR9 Crosslinked Polyethylene/Aluminum/Cross-linked Polyethylene (PEX-AL-PEX) Tubing*

12.0 Acknowledgements

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