



Designation: F3378/F3378M – 22

# Standard Specification for Crosslinkable Polyethylene (CX-PE) Pipe<sup>1</sup>

This standard is issued under the fixed designation F3378/F3378M; 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 ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 This specification covers outside diameter controlled crosslinkable polyethylene (CX-PE) pipe produced in sizes DN 25 to 630 and NPS 1 to 24 in various dimension ratios. Included in this specification are requirements and test methods for the determination of the long-term hydrostatic strength, hydrostatic burst pressure, hydrostatic sustained pressure, UV weathering resistance, initial and ultimate degree of crosslinking, workmanship, and marking.

1.2 This specification shall not be applied to crosslinked products, specifically PEX pipe or tubing.

NOTE 1—CX-PE is a different designation separate from conventional PEX materials, specifically with regard to the crosslinking rate, installation, and commissioning processes.

1.3 The pipe covered by this specification is intended for pressure and non-pressure applications. Fluids such as non-potable water, multi-phase mixed fluids, crude oils, gases, and chemical solutions containing some water are allowed to be transported in pipe made in accordance with this standard. Permissible operating temperatures for commissioned piping systems constructed from CX-PE pipe manufactured in accordance with this specification are  $\leq 200$  °F [93 °C].

1.4 Pipe produced in accordance with this specification is intended to be crosslinked during or after installation. The procedures and practices to be used for the installation and crosslinking of the CX-PE pipe are outside the scope of this specification. Manufacturer's recommendations for the commissioning of CX-PE pipe are used to ensure that the performance of the completed piping system meets design expectations.

NOTE 2—The difference between pipes made in accordance with this specification and PEX pipes made in accordance with Specification F2905 is that the final crosslinking process is completed as part of installation and commissioning as opposed to crosslinking taking place in the manufacturing facility.

1.5 This specification includes requirements to demonstrate a minimum level of performance in service.

<sup>1</sup> This specification is under the jurisdiction of ASTM Committee F17 on Plastic Piping Systems and is the direct responsibility of Subcommittee F17.68 on Energy Piping Systems.

Current edition approved March 1, 2022. Published March 2022. DOI: 10.1520/F3378\_F3378M-22

1.6 Joining of CX-PE pipes made in accordance with this specification is outside the scope of this specification. For guidance on the joining of CX-PE pipe consult Practice F3507 and manufacturer's recommendations.

1.7 This specification references notes, footnotes, and appendixes, which provide non-mandatory explanatory material. Excluding table footnotes which are mandatory, notes, footnotes and information in parentheses shall not be considered as requirements of this specification.

1.8 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.

1.9 *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.*

1.10 *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:<sup>2</sup>

- D638 Test Method for Tensile Properties of Plastics
- 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

<sup>2</sup> 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.

- 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
- 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
- D2837** Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials or Pressure Design Basis for Thermoplastic Pipe Products
- D3895** Test Method for Oxidative-Induction Time of Polyolefins by Differential Scanning Calorimetry
- D4218** Test Method for Determination of Carbon Black Content in Polyethylene Compounds by the Muffle-Furnace Technique
- D4329** Practice for Fluorescent Ultraviolet (UV) Lamp Apparatus Exposure of Plastics
- D4364** Practice for Performing Outdoor Accelerated Weathering Tests of Plastics Using Concentrated Sunlight
- F412** Terminology Relating to Plastic Piping Systems
- F876** Specification for Crosslinked Polyethylene (PEX) Tubing
- 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
- F2905** Specification for Crosslinked Polyethylene (PEX) Line Pipe For Oil and Gas Producing Applications
- F3203** Test Method for Determination of Gel Content of Crosslinked Polyethylene (PEX) Pipes and Tubing
- F3507** Practice for Butt-Fusion Joining of Crosslinkable Polyethylene (CX-PE) Pipe and Tubing
- 2.2 *ANSI Standard*.<sup>3</sup>
- B36.10** Standard for Welded and Seamless Wrought Steel Pipe
- 2.3 *ISO Standards*.<sup>4</sup>
- ISO 14531-1** Plastics pipes and fittings — Crosslinked polyethylene (PE-X) pipe systems for the conveyance of gaseous fuels — Metric series — Specifications — Part 1: Pipes
- ISO 161-1** Thermoplastics pipes for the conveyance of fluids - Nominal outside diameters and nominal pressures - Part 1: Metric series
- ISO 9080** Plastics Piping and Ducting Systems - Determination of The Long-Term Hydrostatic Strength of Thermoplastics Materials in Pipe Form by Extrapolation

2.4 *PPI Standard*.<sup>5</sup>

**TR-3 2021** – HDB/HDS/PDB/SDB/MRS/CRS Policies

2.5 *Military and Federal Standards*.<sup>6</sup>

**FED-STD 123G** Marking for Shipment (Civil Agencies)

**MIL-STD 129P** Military Marking for Shipment and Storage

### 3. Terminology

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

3.2 *Definitions of Terms Specific to This Standard*:

3.2.1 *commission, v*—a series of actions taken after installation to bring a new system into working condition.

3.2.2 *crosslinked pipe, n*—pipe that is crosslinked to a measured gel content level of  $\geq 65\%$ .

3.2.3 *crosslinkable polyethylene, CX-PE, n*—a polyethylene compound that has been chemically modified so that crosslinks will form when the compound is exposed to heat and moisture.

3.2.3.1 *Discussion*—When pipe made from CX-PE reaches a level of crosslinking  $\geq 65\%$  it is considered fully crosslinked and is referred to as crosslinked pipe in accordance with this standard.

3.2.4 *design factor, DF, n*—a number between 0 and 1, that the HDB is multiplied by to determine the HDS. This value is intended to contribute to the certainty that pipe will not fail in the service it is designed for.

3.2.5 *nominal diameter, DN, adj*—a designation for SI unit of outside diameter-controlled pipe sizes that generally comply with outside diameters specified in ISO 161-1.

3.2.6 *nominal pipe size, NPS, adj*—a designation for inch-pound unit outside diameter-controlled pipe sizes that generally comply with outside diameters specified in ANSI B36.10.

3.2.7 *maximum allowable operating pressure, MAOP, n*—the estimated maximum continuous pressure a pipe is capable of withstanding at the maximum operating temperature of a piping system with a high degree of certainty that failure of the pipe will not occur.

### 4. Materials

4.1 *Basic Materials*—CX-PE compound used for production of pipe in accordance with this specification, and for optional co-extruded stripes and layers shall be made from polyethylene compounds which have been made crosslinkable during polyethylene compound manufacture by chemically grafting reactive molecules (for example, vinyl trimethoxy silane) onto polyethylene molecules, or by copolymerization of reactive molecules with ethylene to create a modified polyethylene compound. Compounds and pipes that are produced by other means such as peroxide crosslinking and radiation crosslinking, do not meet the requirements of this specification. CX-PE compounds are crosslinked by added heat and water (see manufacturer's recommendations).

<sup>3</sup> Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, <http://www.ansi.org>.

<sup>4</sup> Available from International Organization for Standardization (ISO), ISO Central Secretariat, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, <https://www.iso.org>.

<sup>5</sup> Available from Plastics Pipe Institute (PPI), 105 Decker Court, Suite 825, Irving, TX 75062, <http://www.plasticpipe.org>.

<sup>6</sup> Available from DLA Document Services, Building 4/D, 700 Robbins Ave., Philadelphia, PA 19111-5094, <http://quicksearch.dla.mil>.

4.2 *Density*—When tested in accordance with 7.4, CX-PE compound shall have a minimum density of 0.033 lb/in<sup>3</sup> or [0.926 g/cm<sup>3</sup>].

4.3 *Degree of Crosslinking*—When CX-PE compound is fully crosslinked and tested in accordance with 7.6, it shall have minimum degree of crosslinking (gel content) of 65 %.

4.4 *Hydrostatic Design Basis (HDB) of Crosslinked Compound*—CX-PE compound in pipe form and fully crosslinked, having a degree of crosslinking (gel content) ≥65 %, shall have an HDB value determined and categorized in accordance with the requirements of Test Method D2837.

4.5 *Thermal Stability*—When CX-PE compound is tested in accordance with D3895 at 392 °F [200 °C], it shall have an oxidative induction time of greater than 20 minutes.

4.6 *UV Resistance and Color:*

4.6.1 The CX-PE materials and any compounds used for striping or outer layer co-extrusion shall contain sufficient stabilizers or carbon black to protect the pipe from UV degradation for a period of not less than six months

**5. Product Qualification**

5.1 Product qualification testing shall be performed to demonstrate the suitability of a CX-PE compound in pipe form in accordance with this specification. Unless otherwise specified, product qualification tests are conducted on any representative size of pipe.

5.2 *Tensile Elongation*—When crosslinked CX-PE pipe is tested in accordance with 7.8, it shall have a tensile elongation at break exceeding 350 %.

5.3 *Hydrostatic Design Basis (HDB) of Crosslinked Pipe*—CX-PE compound in pipe form and fully crosslinked, having a degree of crosslinking (gel content) ≥65 %, shall have an HDB value determined and categorized in accordance with the requirements of Test Method D2837.

5.3.1 The CX-PE crosslinked compound, when fully crosslinked, shall have a minimum HDB value of 1250 psi at 73 °F [8.62 MPa at 23 °C], 800 psi at 180 °F [5.52 MPa at 82 °C] and 630 psi at 200 °F [4.34 MPa at 93 °C].

NOTE 3—Where a Long-Term Hydrostatic Strength (LTHS) value is needed for an application at a temperature intermediate between the established lower HDB and established higher temperature HDB values, interpolation may be used. Refer to the calculations provided in The Plastics Pipe Institute’s Technical Report TR-3, Part D2 -Policy for Determination of Long- Term Strength by Temperature Interpolation

5.4 *Stabilizer Functionality*—The functionality of a stabilizer in a specific CX-PE compound shall be verified by hydrostatic testing of pipe in accordance with 7.9, or with an ISO 9080 data set for pipe made from the compound containing data at 110 °C that shows data points at a stress of greater than or equal to 3.24 MPa and time greater than 8000 h.

5.5 *Chlorine-Thermal Oxidative Stabilization*—Resistance to thermo-oxidation shall be determined for CX-PE pipe in accordance with Test Method F2023. Tubing made in accordance with the dimensional requirements of Specification F876 for NTS ½ shall be tested.

5.6 *UV Resistance and Color:*

5.6.1 The CX-PE materials and any compounds used for striping or outer layer co-extrusion shall contain sufficient stabilizers to protect the pipe from UV degradation for a period of not less than six months.

5.6.2 CX-PE pipe containing between 2.0 wt. % and 3.0 wt. % well dispersed carbon black shall be considered to be stabilized against UV exposure for not less than ten years. The carbon black content in black CX-PE pipe shall be measured in accordance with the requirements of either Test Method D1603 or Test Method D4218.

5.6.3 The maximum UV exposure time for CX-PE pipe not containing a minimum of 2.0 wt. % carbon black, shall be determined by exposing representative pipe samples to natural weathering in accordance with Test Method F2657, or ISO 14531-1 Annex C. Alternatively accelerated UV weathering in accordance with Practice D2565, or Practice D4329, or Practice D4364 are permitted to be used. The minimum total UV exposure tested with shall be 218 MJ/m<sup>2</sup> which shall be considered equivalent to six months of outdoor weathering exposure as described in Test Method F2657. A total solar UV radiation value of 339 MJ/m<sup>2</sup> per year shall be considered the amount of natural UV weathering exposure per year when determining the maximum UV exposure time.

5.6.4 If natural weathering in accordance with Test Method F2657 or ISO 14531-1 Annex C is used, and post exposure testing in accordance with Test Method F2657 is excluded, post exposure testing per the requirements of this standard shall be used to determine maximum UV exposure time. Alternatively, for CX-PE pipes that have a maximum UV exposure time determined when tested in accordance with Test Method F2657 post exposure requirements, no further post exposure testing is required

5.6.5 Following UV weathering exposure, CX-PE pipe shall meet the tensile elongation and OIT requirements of 5.2 and 4.5.

**6. Pipe Requirements**

6.1 The requirements of 6.2 through 6.11 shall apply to CX-PE pipe.

6.2 *Workmanship*—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. Pipe made in accordance with this specification that is co-extruded with an external color layer or external color stripes shall be acceptable.

6.2.1 *Preservation*—Pipe produced in accordance with this specification shall be handled and stored in such a way as to preserve the quality and workmanship of the pipe. This shall include appropriate storage to manage weathering of the pipe (for example, use of tarps over pallets of pipe stored outdoors).

6.3 *Pipe Diameter*—The outside diameter of the pipe shall be in accordance with Table 1 or Table 2 when measured in accordance with Test Method D2122. The outside diameter measurement shall be taken at a distance at least 1.5 times the average outside diameter or 11.8 in. or 300 mm, whichever is less, from the cut end of the pipe. The pipe manufacturer shall

**TABLE 1 DN Size Pipe – Diameter and Wall Thickness, mm**

| Nom. Size<br>(DN) | Outside Diameter |           |      | Minimum Wall Thickness— (tolerance -0/+12 %) |      |       |         |         |       |  |
|-------------------|------------------|-----------|------|--|------|-------|---------|---------|-------|--|
|                   | Minimum          | Tolerance | OOR  | DR 7.4                                       | DR 9 | DR 11 | DR 13.6 | DR 16.2 | DR 17 |  |
| 25                | 25.0             | 0.3       | 1.2  | 3.5  | 3.0  | 2.3   | —       | —       | —     |  |
| 32                | 32.0             | 0.3       | 1.3  | 4.4  | 3.6  | 3.0   | 2.4     | —       | —     |  |
| 40                | 40.0             | 0.4       | 1.4  | 5.5  | 4.5  | 3.7   | 3.0     | 2.5     | 2.4   |  |
| 50                | 50.0             | 0.5       | 1.4  | 6.9  | 5.6  | 4.6   | 3.7     | 3.1     | 3.0   |  |
| 63                | 63.0             | 0.6       | 1.6  | 8.6  | 7.1  | 5.8   | 4.7     | 3.9     | 3.8   |  |
| 75                | 75.0             | 0.7       | 1.6  | 10.3   | 8.4  | 6.8   | 5.6     | 4.6     | 4.5   |  |
| 90                | 90.0             | 0.9       | 1.8  | 12.3   | 10.1 | 8.2   | 6.7     | 5.6     | 5.4   |  |
| 110               | 110.0            | 1.0       | 2.2  | 15.1   | 12.3 | 10.0  | 8.1     | 6.8     | 6.6   |  |
| 125               | 125.0            | 1.2       | 2.5  | 17.1   | 14.1 | 11.4  | 9.2     | 7.7     | 7.4   |  |
| 140               | 140.0            | 1.3       | 2.8  | 19.2   | 15.7 | 12.7  | 10.3    | 8.7     | 8.3   |  |
| 160               | 160.0            | 1.5       | 3.2  | 21.9   | 17.9 | 14.6  | 11.8    | 9.9     | 9.5   |  |
| 180               | 180.0            | 1.7       | 3.6  | 24.6   | 20.1 | 16.4  | 13.3    | 11.1    | 10.7  |  |
| 200               | 200.0            | 1.8       | 4.0  | 27.4   | 22.4 | 18.2  | 14.7    | 12.4    | 11.9  |  |
| 225               | 225.0            | 2.1       | 4.5  | 30.8   | 25.2 | 20.5  | 16.6    | 13.9    | 13.4  |  |
| 250               | 250.0            | 2.3       | 5.0  | 34.2   | 27.9 | 22.7  | 18.4    | 15.5    | 14.8  |  |
| 280               | 280.0            | 2.6       | 9.8  | 38.3   | 31.3 | 25.4  | 20.6    | 17.3    | 16.6  |  |
| 315               | 315.0            | 2.9       | 11.1 | 43.1   | 35.2 | 28.6  | 23.2    | 19.5    | 18.7  |  |
| 355               | 355.0            | 3.4       | 12.5 | 48.5   | 39.7 | 32.2  | 26.1    | 21.9    | 21.1  |  |
| 400               | 400.0            | 3.6       | 14.0 | 54.7   | 44.7 | 36.3  | 29.4    | 24.7    | 23.8  |  |
| 450               | 450.0            | 4.2       | 15.6 | 61.5   | 50.3 | 40.9  | 33.1    | 27.8    | 26.7  |  |
| 500               | 500.0            | 4.6       | 17.5 | —  | 55.8 | 45.4  | 36.8    | 30.9    | 29.7  |  |
| 560               | 560.0            | 5.2       | 19.6 | —  | 62.5 | 50.8  | 41.2    | 34.6    | 33.2  |  |
| 630               | 630.0            | 5.8       | 22.1 | —  | 70.3 | 57.2  | 46.3    | 38.9    | 37.4  |  |

**TABLE 2 NPS Pipe – Diameter and Wall Thickness, in.**

| Nominal<br>Pipe Size<br>(NPS) | Outside Diameter |           |      | Minimum Wall Thickness – tolerance +12 % |        |       |       |         |       |  |
|-------------------------------|------------------|-----------|------|--|--------|-------|-------|---------|-------|--|
|                               | Average          | Tolerance | OOR  | DR 7                                     | DR 7.3 | DR 9  | DR 11 | DR 13.5 | DR 17 |  |
| 1                             | 1.315            | ±0.005    | 0.03 | 0.188                                    | 0.180  | 0.146 | 0.120 | —       | —     |  |
| 1 ¼                           | 1.660            | ±0.005    | 0.03 | 0.237                                    | 0.227  | 0.184 | 0.151 | 0.123   | —     |  |
| 1 ½                           | 1.900            | ±0.006    | 0.06 | 0.271                                    | 0.260  | 0.211 | 0.173 | 0.141   | —     |  |
| 2                             | 2.375            | ±0.006    | 0.06 | 0.339                                    | 0.325  | 0.264 | 0.216 | 0.176   | 0.140 |  |
| 3                             | 3.500            | ±0.008    | 0.06 | 0.500                                    | 0.479  | 0.389 | 0.318 | 0.259   | 0.206 |  |
| 4                             | 4.500            | ±0.009    | 0.10 | 0.643                                    | 0.616  | 0.500 | 0.409 | 0.333   | 0.265 |  |
| 6                             | 6.625            | ±0.011    | 0.12 | 0.946                                    | 0.908  | 0.736 | 0.602 | 0.491   | 0.390 |  |
| 8                             | 8.625            | ±0.013    | 0.24 | 1.232                                    | 1.182  | 0.958 | 0.784 | 0.639   | 0.507 |  |
| 10                            | 10.750           | ±0.015    | 0.24 | 1.536                                    | 1.473  | 1.194 | 0.977 | 0.796   | 0.632 |  |
| 12                            | 12.750           | ±0.017    | 0.28 | 1.821                                    | 1.747  | 1.417 | 1.159 | 0.944   | 0.750 |  |
| 14                            | 14.000           | ±0.063    | —    | 2.000                                    | 1.918  | 1.556 | 1.273 | 1.037   | 0.824 |  |
| 16                            | 16.000           | ±0.072    | —    | 2.286                                    | 2.192  | 1.778 | 1.455 | 1.185   | 0.941 |  |
| 18                            | 18.000           | ±0.081    | —    | 2.571                                    | 2.466  | 2.000 | 1.636 | 1.333   | 1.059 |  |
| 20                            | 20.000           | ±0.090    | —    | 2.857                                    | 2.740  | 2.222 | 1.818 | 1.481   | 1.176 |  |
| 22                            | 22.000           | ±0.099    | —    | 3.143                                    | 3.014  | 2.444 | 2.000 | 1.630   | 1.294 |  |
| 24                            | 24.000           | ±0.108    | —    | 3.429                                    | 3.288  | 2.667 | 2.182 | 1.778   | 1.412 |  |

ensure that any change in diameter of the pipe during cross-linking will result in crosslinked pipe that conforms to the tolerances stated in **Table 1** or **Table 2**.

**6.3.1 Toe-In**—When measured in accordance with Test Method **D2122**, the outside diameter at the cut end of the pipe shall not be more than 1.5 % smaller than the outside diameter in accordance with **Table 1** or **Table 2**.

**6.3.2 Ovality**—Pipe ovality (elliptical shape) when exiting production line processing equipment but before coiling or packaging for shipment shall not exceed 5 % when determined in accordance with **7.10**.

**NOTE 4**—Ovality is a field correctible condition that results from packaging or storage. When coiled, pipe will deflect to an oval or elliptical profile, and when packaged or stored, higher DR pipe may deflect to an oval or elliptical profile. If necessary, commercially available equipment can be applied to minimize percent ovality during field joining or installation.

**6.3.3 Out of Roundness (OOR)**—The measured out of roundness shall be less than or equal to the OOR specified in

**Table 1** or **Table 2** for the applicable size pipe. Measure out of roundness in accordance with Test Method **D2122**.

**NOTE 5**—Irregular outside surface conditions from the extrusion line processing equipment that are not field correctible can affect the suitability of pipe for joining with devices that secure or seal to the pipe outside surface, especially electrofusion devices.

**6.4 Pipe Wall Thickness**—Pipe wall thickness shall be as specified in **Table 1** or **Table 2** when measured in accordance with Test Method **D2122**.

**6.5 Special Sizes**—Outside diameter or wall thickness not specified in **Table 1** or **Table 2** shall be acceptable by agreement between the manufacturer and the purchaser. If not otherwise specified, the total tolerance on special size outside diameter shall not exceed +0.90 % of the minimum special outside diameter or ±0.45 % of the average special outside diameter. If not otherwise specified, the tolerance on special size wall thickness shall be +12 % of the minimum special size wall thickness for NPS 12 and smaller special sizes.



6.6 *Short Term Strength*—CX-PE pipe specimens shall be tested in accordance with 7.5 to determine the test pressure,  $P_T$ , at 73 °F or [23 °C] for each pipe size and SDR or DR. The calculation of the hoop stress shall be made using the initially measured minimum wall thickness and diameter of the pipe. At specimen failure, the hoop stress,  $S$ , shall exceed 2700 psi or [18.6 MPa].

6.7 *Degree of Crosslinking:*

6.7.1 Within five days prior to shipment by the manufacturer, the degree of crosslinking (gel content) of minimally crosslinked CX-PE pipe shall be less than 30 % when tested in accordance with 7.6.

6.7.2 In the event that prior to shipment, the pipe manufacturer determines that CX-PE pipe is crosslinked to greater than 30 %, the manufacturer is permitted to ship the pipe with agreement from the purchaser to accept pipe with higher than specified degree of crosslinking. In this case the pipe shall be clearly marked to indicate that joining by butt fusion is not recommended for the batch of CX-PE pipe in question.

6.7.3 Fully crosslinked CX-PE pipe shall have a degree of crosslinking between 65 % and 89 % inclusive when tested in accordance with 7.6. The pipe manufacturer shall use hot water or low-pressure steam after extrusion to crosslink pipe samples prior to testing.

6.8 *Sustained Hydrostatic Strength (165 h)*—CX-PE pipe specimens that are minimally crosslinked (<30 %) shall be tested in accordance with 7.7 using Eq 1 to determine the test pressure,  $P_T$ . The specimens shall not fail in less than 165 h at a hoop stress,  $S$ , of at least 670 psi [4.56 MPa]. This test shall be repeated at least twice annually at approximately half-year intervals by the pipe manufacturing facility on representative size pipe.

6.9 *Rework Material*—Rework of un-crosslinked CX-PE pipe is permitted in the production of CX-PE pipe made in accordance with this specification. It shall only be re-work from the manufacturer's own production of the same lot of CX-PE compound and shall be re-worked within 72 h of original production. The maximum quantity of rework CX-PE is 7 % by weight in the final pipe. Re-work material shall not be contaminated, nor have been exposed to elevated processing temperatures, or long residence time in extrusion machinery. The re-worked material shall be ground immediately before combination with virgin material and re-use to prevent more rapid ambient crosslinking because of increased surface area.

NOTE 6—The use of re-work material is possible because the CX-PE compound is formulated to control crosslinking rate so that it will not crosslink significantly at ambient conditions for several days. Time limits for the use of reworked material are set to preclude the use of partially crosslinked rework material.

6.10 *Sample Retention*—For every production lot, two pieces of pipe no less than 48 in. [1200 mm] in length each shall be retained. Retained sample pipe shall be stored in the same manner as produced pipe. Retained pipe shall be available for confirmatory testing when required and shall be retained for no less than two years.

6.11 *Carbon Black Content*—Black CX-PE pipe shall contain carbon black at between 2.0 wt. % and 3.0 wt. %. The

carbon black content in black CX-PE pipe shall be measured in accordance with the requirements of either Test Method D1603 or Test Method D4218.

**7. Test Methods**

7.1 *Conditioning*—Specimens shall be conditioned in circulating air at 73 °F  $\pm$  4 °F or [23 °C  $\pm$  2 °C] and  $\leq$  55 % relative humidity for not less than 16 h prior to testing, for those tests where conditioning is required and not otherwise specified.

7.2 *Test Conditions*—Tests shall be conducted at 73 °F  $\pm$  4 °F or [23 °C  $\pm$  2 °C] and  $\leq$  55 % relative humidity, unless otherwise specified in the test methods or in this specification.

7.3 *Sampling:*

7.3.1 Enough pipe 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.

7.3.2 It is permitted to test CX-PE pipe properties specified in Section 5 of this specification using pipe or tubing samples made in dimensions that do not conform with this specification. (For example, hydrostatic, thermo-oxidative resistance, and UV resistance testing are permitted to be performed on NTS ½ SDR 9 tubing.)

7.4 *Density*—The density of CX-PE pipe shall be determined in accordance with Test Method D1505, or Test Methods D792, using three specimens. Specimens for these tests shall be taken from representative pipe made from the compound.

7.5 *Short-Term Strength*—Test pipe specimens in accordance with Test Method D1599 without regard to humidity. Failure shall occur between 60 s and 70 s and shall be ductile. For NPS 3 or DN 90 and larger pipe, testing in accordance with Test Method D2290 without regard to humidity, in lieu of Test Method D1599 shall be acceptable.

7.6 *Degree of Crosslinking:*

7.6.1 For tests intended to determine the crosslinking level of CX-PE pipe, test specimens shall be prepared without conditioning.

7.6.2 For tests intended to determine that the compound is crosslinked to between 65 % and 89 %, samples shall be conditioned in accordance with 7.1 after the crosslinking process has been performed.

7.6.3 Test the specimens in accordance with Test Method F3203 or Test Methods D2765 Method B with the only deviation being specimen preparation (see Note 7). For the purposes of this specification the degree of crosslinking is the measured gel content in accordance with these test methods.

NOTE 7—The preparation of specimens for gel content testing may be performed in many ways that will give valid results. If deviation from standard specimen preparation takes place, it is recommended to maintain a record of the specimen preparation method used.

7.7 *Sustained Hydrostatic Strength:*

7.7.1 The size of CX-PE minimally crosslinked pipe sampled for this test shall be less than or equal to NPS 4 or DN 110. Randomly select five specimens of pipe. Each specimen shall be at least ten times the nominal diameter in length, but not less than 12 in. or [305 mm] or more than 36 in. or [914

mm] between end closures and containing some portion of the permanent marking on the pipe.

7.7.2 Use the following equation to determine the test pressure,  $P_T$ :

$$P_T = \frac{2 \times S}{(DR - 1)} \quad (1)$$

7.7.3 Test the individual specimens in accordance with Test Method **D1598** with water in a water bath at 200 °F [93 °C] or 95 °C [203 °F] and the pressure specified. Specimens shall be conditioned for 30 min to 65 min prior to being pressurized.

7.7.4 Failure (ballooning, rupture, seepage, or weeping) as defined in Test Method **D1598** of one or more of the specimens tested in less than the time specified in this specification shall constitute failure of the test.

#### 7.8 Tensile Elongation:

7.8.1 Five specimens shall be taken from the pipe wall in the longitudinal direction and evenly spaced around the circumference. Specimens shall be conditioned in accordance with **7.1** and tested in accordance with Test Method **D638**. All test specimens shall be prepared in the same manner and a description of the specimen collection and preparation shall be included in the test report.

7.8.2 Depending on sample pipe wall thickness, it is acceptable for tension test specimens to be machined to remove inside or outside wall material or both to achieve specified thickness.

7.8.3 It is permissible to use tensile specimens that do not conform to the dimensions for tension test specimens in accordance with Test Method **D638**, so long as the quality of the specimen preparation conforms to the general principles for specimen preparation expressed in Test Method **D638**.

#### 7.9 Stabilizer Functionality:

7.9.1 Test six CX-PE fully crosslinked pipe specimens (crosslinked to  $\geq 65\%$ ) continuously for a minimum of 3000 h at a minimum hoop stress of 335 psi at 248 °F or [2.3 MPa at 120 °C], or for a minimum of 8000 h at a minimum hoop stress of 470 psi at 230 °F or [3.24 MPa at 110 °C].

7.9.2 Test the specimens in accordance with Test Method **D1598** at either of the temperature and hoop stress conditions in **7.9.1**. The internal medium shall be water and the external medium shall be air. Failure as defined in Test Method **D1598** of any one of the specimens constitutes failure of the test.

7.10 *Ovality*—Determine ovality in accordance with Test Method **D2122**. Measure the average outside diameter with a circumferential wrap tape (pi-tape). Except as provided in **7.10.1**, determine the maximum and minimum diameter at the same location where the average diameter was measured with calipers or a tape measure accurate to  $\frac{1}{32}$  in. [0.80 mm] for 16 in. and smaller pipes or to  $\frac{1}{16}$  in. [1.59 mm] for larger pipes. When minimum (or maximum) diameter is determined, rotate calipers or tape measure approximately 90 degrees around the pipe circumference to determine the corresponding maximum (or minimum) diameter. Calculate ovality by subtracting the minimum diameter from the maximum diameter, dividing the difference by the measured average outside diameter, and multiplying by one hundred.

7.10.1 When maximum and minimum diameter are measured at the end of the pipe, the average outside diameter shall be measured 11.8 in. [300 mm] or one pipe diameter, whichever is less, from the end of the pipe so that the average outside diameter measurement is not affected by toe-in.

7.11 *Out of Roundness*—Determine out of roundness in accordance with Test Method **D2122**.

7.12 *Carbon Black Content*—Determine the carbon black content in black CX-PE pipe in accordance with either Test Method **D1603** or Test Method **D4218**.

## 8. Marking

8.1 *Quality of Marking*—Markings shall be applied in some permanent manner to remain legible under normal handling and installation practice. The marking shall not reduce the wall thickness to less than the minimum value for the pipe, shall not affect the long-term strength of the pipe, and shall not provide leakage channels for joining devices that seal or join to the outside surface of the pipe.

8.2 Marking on the pipe shall include the following, spaced at intervals of not more than 5 ft [1.5 m]:

8.2.1 Manufacturer's name (or trademark)

8.2.2 Pipe size and sizing system – DN or NPS – (for example, “DN 90” or “NPS 12”).

8.2.3 Standard dimension ratio or dimension ratio, (for example, “SDR 9”).

8.2.4 Production code indicating the date of production, manufacturing location and production line.

8.2.4.1 When requested by the purchaser, the manufacturer shall provide a decoding explanation for the production code.

8.2.4.2 In the production code, the date shall be first and shall be clearly recognizable such as “10 OCT 2020”, or “OCT 10, 2020”. All digits of the year shall be printed, and the month shall be printed in letters, not numerals.

8.2.5 The standard designation, ASTM F3378/F3378M.

8.2.6 Maximum UV exposure time determined in accordance with **5.6**, for example “4 YRS MAX UV”.

8.2.7 Maximum HDB rating temperature, when fully crosslinked in accordance with **5.3** in °C or °F, (for example “MAX 200 °F” or “MAX 93 °C”).

8.2.8 A statement that butt fusion is not to be performed after the pipe is crosslinked (for example, “NO BUTT FUSION AFTER X-LINKED”).

8.2.9 Markings referring to pipe pressure rating such as pressure rating (PR), working pressure (WP), working pressure rating (WPR), pressure class (PC), or nominal pressure (PN or NP) are not to be used.

8.2.10 Any additional information such as certification agency certification marks.

## 9. Quality Assurance and Certification:

9.1 When pipe product is marked with this designation, ASTM F3378/F3378M, the pipe 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.

9.2 The purchaser of CX-PE pipe made in accordance with this specification shall be furnished with a pipe manufacturer's certification document stating the date or dates of pipe production and the maximum permitted storage time for the CX-PE pipe. This is required without regard to requirements of a purchase order or contract. The CX-PE manufacturer shall advise the purchaser that the CX-PE pipe will continue to crosslink and that they are responsible for installing the pipe prior to the expiration of the maximum permitted storage time.

9.3 If required by the authority having jurisdiction, CX-PE pipe produced in accordance with this specification shall be evaluated and certified by a certification agency acceptable to the authority having jurisdiction. The certification evaluation shall be in accordance with the requirements of this specification.

9.4 The pipe manufacturer shall have a documented quality program that at a minimum includes a system for the source traceability and verification of CX-PE compounds used in the manufacture of CX-PE pipe meeting the requirements of this specification, and that documents test results demonstrating that products comply with the requirements of this specification. The quality program documentation system shall also document product date of manufacture and the CX-PE compound used for the CX-PE pipe made on that date.

## 10. Keywords

10.1 crosslinkable polyethylene; crosslinked polyethylene; CX-PE; energy piping; hydrostatic stress; PEX; pressure; pipe

## SUPPLEMENTARY REQUIREMENTS

### GOVERNMENT/MILITARY PROCUREMENT

These requirements apply only to federal government civil/military procurement, not domestic sales, or transfers.

#### S1. Responsibility for Inspection

S1.1 Unless otherwise specified in the contract or purchase order, the producer is responsible for performance of all inspection and test requirements specified herein. The producer shall use its own or any other suitable facilities for the performance of the inspection and test requirements specified herein, unless the purchaser disapproves. 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 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 materials shall be packaged in accordance with the supplier's standard practices in a manner ensuring arrival at destination in satisfactory condition and which will be acceptable to the carrier at lowest rates. Containers and packing 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 123G for civil agencies and MIL-STD 129P for military agencies.

NOTE S2.1—The inclusion of U.S. Government procurement requirements should not be construed as an indication that the U.S. Government uses or endorses the products described in this specification.

## APPENDIXES

### (Nonmandatory Information)

#### X1. UV LABELING GUIDELINES FOR CX-PE PIPE

X1.1 CX-PE pipe will deteriorate slowly when exposed to direct sunlight unless it is compounded with additives to produce indefinite UV protection. If the time between manufacture and installation could exceed 6 months, and the pipe does not have indefinite UV protection built into the compound, CX-PE pipe should be protected from UV exposure by storage in a shelter, or by covering the pipe with a UV

blocking material. To inform users about the need to prevent overexposure to sunlight (UV light), it is recommended that a UV CAUTION label be applied to CX-PE pipe by the manufacturer.

X1.2 The recommended text of the UV caution label is: "Keep CX-PE pipe under protective cover until time of