



Designation: F3378/F3378M – 22

Standard Specification for Crosslinkable Polyethylene (CX-PE) Pipe¹

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 (ϵ) 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 ≤ 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.

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:²

- 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

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

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*.³

B36.10 Standard for Welded and Seamless Wrought Steel Pipe

2.3 *ISO Standards*.⁴

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*.⁵

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

2.5 *Military and Federal Standards*.⁶

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).

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

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

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

⁶ 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/in³ or [0.926 g/cm³].

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/m² 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/m² 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 (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 Pipe Size (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 manufacturers 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

installation. Ensure that exposure to sunlight prior to installation does not exceed the maximum recommended UV exposure time of "X." In this case "X" is the maximum cumulative time as recommended by the pipe manufacturer for direct sunlight exposure without harm to the long-term performance characteristics of the CX-PE pipe. This ("X") is the amount of time

printed on the pipe in accordance with 8.2.6.

X1.3 The recommended text may be incorporated into existing labels with other information. The universal "nosun" symbol may be shown in color, black-and-white or grayscale, and should be positioned close to the recommended text.

X2. OPTIONAL PERFORMANCE QUALIFICATION AND IN-PLANT QUALITY-CONTROL PROGRAM

X2.1 Scope

X2.1.1 The following program covers an optional performance qualification and in-plant quality control program for the manufacture of CX-PE pipe produced in accordance with this specification.

X2.2 Performance Qualifications

X2.2.1 All requirements and tests should be performed on pipe made using each CX-PE compound formulation in accordance with the requirements of this specification.

TABLE X2.1 Suggested Quality-Control Program

Property	Minimum Frequency	Requirements (Section)
Workmanship	Continuously	6.2
Dimensions	Hourly or once per coil	6.3 and 6.4
Short Term Strength	Two weeks / Once per production run	6.6
Degree of Crosslinking	7 days of production ^A	6.7
Sustained Hydrostatic Strength (165 h)	Twice yearly ^B	6.8
Stabilizer Functionality	Initially & every five years ^B	5.4
Hydrostatic Design Basis ^C	Initially & every five years ^B	5.3
Tensile elongation	Initially & every three years	5.2

^A May be tested at any time after extrusion to allow for testing only once prior to shipment in accordance with 6.7.

^B Only required on one extrusion line to maintain material and extrusion process qualification.

^C Only test one production lot and only to >6000 h at 200 °F or [93 °C].

dance with the requirements of this specification. The test results may be independently certified, and a test report may be made available on request. Appropriate representative sizes should be tested.

X2.3 In-Plant Quality Control

X2.3.1 In accordance with the manufacturer's documented quality program, quality-control tests should be run for each extrusion. The tests and testing frequency outlined in Table X2.1 are recommended. Only one size of pipe is required to be tested during a frequency period per compound per extrusion line and may be the smallest size produced by the pipe manufacturer. Responsibility for testing is expected to be shared between the pipe extruder and the compound manufacturer for the product properties that are tested at intervals longer than once per year.

X2.3.2 In accordance with the manufacturer's documented quality program, test results are to be recorded, filed, and maintained for not less than five years. Should a specimen fail to meet the requirement in any test, production should be sampled back to the previous acceptable test result and tested to determine which interim production samples do not meet the requirement. The production that is represented by samples that do not meet the requirements of this specification are then rejected.

X3. RECOMMENDED REQUALIFICATION STEPS UPON FORMULATION CHANGES

X3.1 Scope

X3.1.1 The following recommendations cover changes to the formulation and proposed testing.

X3.2 Formulation Changes

X3.2.1 Major formulation changes such as substitution of the base PE material used to produce a CX-PE compound require re-testing of the compound in accordance with Sections 4 and 5.

X3.3 Colorant Changes

X3.3.1 Changes to the colorant used are permitted with no additional testing when the substituted colorant is not liquid based, the substituted colorant pigment particle size is the same or smaller, the substituted colorant is chemically inert with

regard to crosslinking reactions, any quantity change in colorant is less than 50 % by weight from the original amount, and the overall concentration of the colorant does not exceed 0.5 % by mass of the compound. Organic based colorants are permitted to be substituted with organic based colorants and inorganic based colorants are permitted to be substituted with inorganic based colorants. Otherwise, the compound shall be tested to demonstrate conformance with Section 5.

X3.4 Stabilizer Substitutions

X3.4.1 The stabilization of a CX-PE pipe is dependent on the overall quantity of thermal oxidative stabilizers and UV absorbers and stabilizers present in the pipe and the ratios of the specific stabilizers comprising of this quantity. Substitutions of stabilizers from different manufacturers but with the

same CAS numbers and purity are permitted with no additional testing. Other changes to the stabilizer package for a CX-PE compound are permitted as follows.

X3.4.2 If stabilization performance has been demonstrated in accordance with 5.4, 5.5, and 5.6 for a CX-PE pipe formulation using a known combination of stabilizers by a manufacturer, other CX-PE compounds using the same combination of stabilizers at the same overall concentration and produced by the same manufacturer are permitted to be assumed to have the same stabilization performance.

X3.4.3 Changes in stabilizers (changes between additives with different CAS numbers) or decreases in the overall amount of stabilizer content should be retested in accordance

with 4.5, 5.4, 5.5, and 5.6 (OIT, stabilizer functionality, chlorine stabilization and UV resistance) to demonstrate equivalent performance.

X3.4.4 An increase in the amount used of one or more of the stabilizers in the stabilization package does not require retesting except when the overall percentage of the stabilization package in the compound is or will be greater than 1.2 % by weight of the compound.

X3.5 Catalyst and Process Aid Changes

X3.5.1 Catalysts and process aids are permitted to be substituted and changed so long as the overall quantity of the active ingredients comprising catalysts and process aids together do not exceed 0.2 % by weight in the compound.

X4. HYDROSTATIC DESIGN STRESSES AND ALLOWABLE OPERATING PRESSURE

X4.1 Hydrostatic stress testing data is analyzed using Test Method D2837 and ISO 9080. These standards should be referred to for more information regarding the method of test and other criteria used in developing HDB and HDS values.

X4.2 The hydrostatic design stresses determined apply to CX-PE pipe after complete crosslinking meeting the requirements of this specification when water is the fluid in the pipes. Alternative design and service fluid design factors (F_S) may be considered and used based on the required design life and the fluid transported in the pipes.

X4.3 In determination of the fluid service factor (F_S), it is recommended that chemical resistance tests be performed, and the compound manufacturer be consulted. There are many fluids that are not aggressive toward PE or CX-PE which will allow a F_S of 1.0 to be used; however, if the fluid being transferred contains hydrocarbons at greater than 2 %, a F_S of 0.5 is recommended to be used.

X4.4 The following is an example of a determination of the maximum allowable operating pressure (MAOP) of a cross-linked pipe produced from CX-PE compound in accordance with this standard and commissioned in accordance with

manufacturer's recommendations.

X4.4.1 Determine the maximum operating temperature for the system and then determine the HDB at that temperature by interpolation (see Note 5).

X4.4.2 Determine the design factor (DF) to be used for the system, considering the CX-PE compound used. The pipe manufacturer should be able to advise on an appropriate design factor to use.

X4.4.3 Determine the fluid service factor (F_S) and the dimension ratio (DR) of the pipe. In this example the fluid in the pipes is water so the fluid service factor is 1.0. The DR in this example will be 11. The DR is found printed on the pipe.

X4.4.4 Calculate the (MAOP) of the crosslinked pipe at a temperature with a service fluid using Eq X4.1.

$$\text{MAOP}_{\text{Temp}} = \frac{2 \times \text{HDB}_{\text{Temp}} \times \text{DF} \times F_S}{(\text{DR} - 1)} \quad (\text{X4.1})$$

For example, DR 11 pipe with an HDB of 1600 psi @ 73°F with a DF of 0.5 and a F_S of 1.0:

$$\begin{aligned} \text{MAOP}_{73^\circ\text{F}} &= \frac{2 \times 1600\text{psi} \times 0.50 \times 1.00}{(11 - 1)} \\ \text{MAOP}_{73^\circ\text{F}} &= 160\text{psi} \end{aligned}$$

X5. ENVIRONMENTAL STORAGE TIME DETERMINATION FOR CX-PE PIPE

X5.1 *Environmental Storage Time*—As crosslinking rates are dependent on climate, wall thickness and CX-PE compound, representative CX-PE pipe samples, having the thinnest wall thickness should be produced and stored outdoors with no covering to determine the allowable environmental exposure time in which pipe remains substantially uncrosslinked. If pipe that is on reels is being tested, specimens should be taken from the outside of the reel end of the pipe. The storage site for this test should have climatic norm peak summer month (July in northern Hemisphere) average hourly

dew point of at least 55 °F [13 °C]. After storage for a minimum of six months with the highest average temperatures in a year, the gel content should be tested on the exposed sample pipe in accordance with 7.6 and should be <30 %.

X5.2 If regrind is used in the production of CX-PE pipe in accordance with 6.9, it may affect the storage life of the pipe. The pipe manufacturer should conduct tests to determine if the use of regrind CX-PE material in the production of CX-PE pipe significantly affects the environmental storage life of the pipe.



F3378/F3378M – 22

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