INTERNATIONAL

Designation: F3497 − 21

Standard Test Method for Evaluating the Oxidative Resistance of Polypropylene (PP) Piping Systems to Hot Chlorinated Water[1]

This standard is issued under the fixed designation F3497; 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 test method describes the general requirements for evaluating the long-term, chlorinated water, oxidative resistance of polypropylene (PP) piping produced in accordance with Specification F2389 used in hot-and-cold water distribution systems by exposure to hot, chlorinated water. This test method outlines the requirements of a pressurized flow-through test system, typical test pressures, test-fluid characteristics, failure type, and data analysis.

NOTE 1—Other known disinfecting systems (chlorine dioxide, ozone, and chloramines) are also used for protection of potable water. Free-chlorine is the most common disinfectant in use today. A PPI research project examined the relative aggressiveness of free chlorine and chloramines on PEX pipes, both at the same 4.0 ppm concentration and the same test temperatures. The results of the testing showed pipe failure times approximately 40 % longer when tested with chloramines compared to testing with free chlorine, at the tested conditions. Based on these results, the data suggests that chloramines are less aggressive than free chlorine to PEX pipes. This note is provided for information regarding testing different disinfecting systems on PEX tubing using Test Method F2023. The PPI research project did not include testing of polypropylene piping.

NOTE 2—This test method is based on Test Method F2023 and results from this method can be used for direct comparison with previous results on PP piping materials tested in accordance with Test Method F2023.

1.2 This test method is applicable to PP piping 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.

1.3 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard

1.4 The following precautionary caveat pertains only to the test method portion, Section 12, of this specification. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *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]

D1600 Terminology for Abbreviated Terms Relating to Plastics

D2122 Test Method for Determining Dimensions of Thermoplastic Pipe and Fittings

F412 Terminology Relating to Plastic Piping Systems

F2023 Test Method for Evaluating the Oxidative Resistance of Crosslinked Polyethylene (PEX) Pipe, Tubing and Systems to Hot Chlorinated Water

F2389 Specification for Pressure-rated Polypropylene (PP) Piping Systems

2.2 *ISO Standards:*[3]

ISO 9080 Thermoplastic Pipe for Transport of Fluids—Methods of Extrapolation of Hydrostatic Stress Rupture Data to Determine the Long Term Strength of Thermoplastic Pipe

ISO 13760 Plastic Pipe for the Conveyance of Fluids Under Pressure—Miner's Rule—Calculation Method for Cumulative Damage

2.3 *American Water Works Association (AWWA) Document:*[4]

1996 WATER:\STATS Survey

[1] This test method is under the jurisdiction of ASTM Committee F17 on Plastic Piping Systems and is the direct responsibility of Subcommittee F17.40 on Test Methods.

Current edition approved Dec. 15, 2021. Published January 2022. DOI: 10.1520/E3497–21

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

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

[4] Available from American Water Works Association (AWWA), 6666 W. Quincy Ave., Denver, CO 80235, http://www.awwa.org.

2.4 *NSF/ANSI Standard:*[5]
NSF/ANSI 14 Plastic Piping System Components and Related Materials

3. Terminology

3.1 *Definitions:*

3.1.1 Definitions are in accordance with Terminology F412 and abbreviations are in accordance with Terminology D1600, unless otherwise indicated.

3.1.2 *brittle failure (Stage II), n*—failure in the pipe or tubing wall that is characterized by little or no material deformation in the failure area and is the result of a single crack emanating from the interior of the pipe or tubing to the outside surface typically resulting in a pinhole leak, see Fig. 1. For some materials, brittle failure could be indicated by weeping at the pipe surface. Brittle failures produced with this test method shall not be used for data analysis.

3.1.3 *ductile failure (Stage I), n*—failure in the pipe or tubing wall that is characterized by obvious localized deformation of the material visible with the unaided eye, see Fig. 1.

3.1.3.1 *Discussion*—Ductile failures produced with this test method shall not be used for data analysis.

3.1.4 *environmental or oxidative failure (Stage III), n*—failure in the pipe or tubing wall characterized by a large number of cracks emanating from the interior surface of the pipe or tubing wall, see Fig. 1. For some materials, oxidative failure could be indicated by weeping at multiple locations on the pipe surface.

3.1.4.1 *Discussion*—Stage III failures may also be identified by a color shift in the failure area. Identification of environmental or oxidative failure, when not obvious by inspection with the unaided eye, can be performed with a 25× microscope or other similar device yielding the same level of magnification. Only Stage III environmental or oxidative failures shall be used for data analysis. In some cases, thinning of the specimen wall prior to failure may result in localized stresses sufficiently high to induce micro-ductility at the leading edge of the fracture during final rupture. This micro-ductility does not indicate a mixed-mode failure which is evidenced by a combination of brittle and macroscopic ductile failure modes and these specimens are included as Stage III failures.

3.1.5 *hot-and-cold water distribution system, n*—a combination of components such as pipe or tubing, fittings, valves, and so forth, that when installed as a complete system, make up the interior water supply system of a commercial or residential structure.

3.1.6 *long-term oxidative resistance, n*—the extrapolated time-to-failure prediction as determined by analysis of time-to-failure test data by multiple linear regression utilizing. Where applicable, application of Miner's Rule in accordance with ISO 13760 can be used to estimate time-to-failure at several differing conditions of temperature or stress, or both.

3.1.7 *multiple linear regression, n*—a three coefficient mathematical model used to analyze time-to-failure data from different temperatures and stresses to extrapolate projected time-to-failure at selected temperatures or stresses.

3.1.8 *miner's rule, n*—a mathematical method for estimating the cumulative, irreversible damage that results from exposure to each of several differing conditions of stress or temperature, or both.

3.1.9 *nominal wall thickness*—the wall thickness of a pipe determined by dividing the nominal size (diameter) by the dimension ratio (DR).

3.1.10 *oxidation reduction potential (ORP), n*—a measure of the total oxidizing power of a solution by means of a platinum-redox electrode. For a further explanation of ORP see Appendix X2.

3.1.11 *unaided eye, n*—observable without visual enhancement beyond correction for normal vision.

4. Summary of Test Method

4.1 The PP piping or piping/fitting assemblies are exposed to pressurized test-fluid until failure. The fittings used are representative of actual fittings used in the PP system, or are fittings made from a material essentially inert to the effect of the test fluid. All time-to-fail data used for analysis shall be the

[5] Available from NSF International, P.O. Box 130140, 789 N. Dixboro Rd., Ann Arbor, MI 48105, http://www.nsf.org.

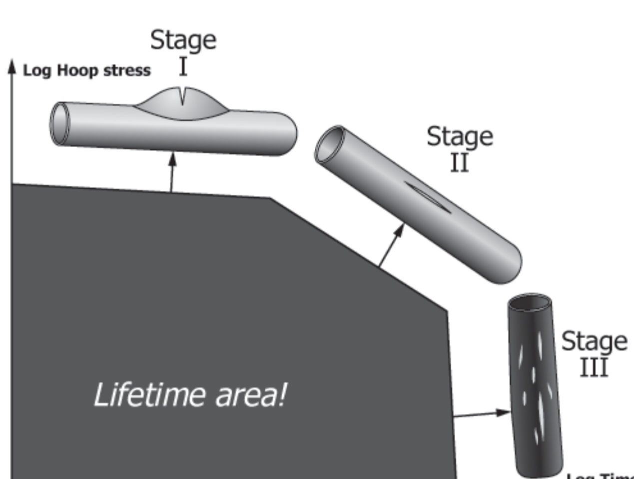

FIG. 1 Pictorial Illustration of Failure Types

result of oxidative degradation (Stage III). A minimum number of test temperature and hoop stress conditions are required to allow accurate data analysis and time-to-failure extrapolations.

5. Significance and Use

5.1 Environment or oxidative time-to-fail data derived from this test method, analyzed in accordance with Section 13, are suitable for extrapolation to typical end-use temperatures and hoop stresses. The extrapolated value(s) provides a relative indication of the resistance of the tested PP piping or system to the oxidative effects of hot, chlorinated water for conditions equivalent to those conditions under which the test data were obtained. The performance of a material or piping product under actual conditions of installation and use is dependent upon a number of factors including installation methods, use patterns, water quality, nature and magnitude of localized stresses, and other variables of an actual, operating hot-and-cold water distribution system that are not addressed in this test method. As such, the extrapolated values do not constitute a representation that a PP pipe or system with a given extrapolated time-to-failure value will perform for that period of time under actual use conditions.

6. Apparatus

6.1 *Pressurized Flow-Through Test System*—A system comprised of the necessary pump(s), fittings, piping, heaters, sensors, and meters that is capable of maintaining the required test pressures within the tolerance specified in 9.1.3, the required test temperatures within the tolerance of 9.1.2, and flow the test-fluid through the specimens continually at a flow rate within the tolerance specified in 9.1.4. Cyclic pressure variations, such as those produced by some pumping systems, shall not produce pressure excursions that exceed the tolerance stated in 9.1.3.

6.1.1 *Recirculating Test System*—A flow-through test system that repeatedly reconditions the test-fluid and passes it through the specimens. For purposes of this test method, the test-fluid shall be monitored at a sufficient frequency to ensure that it continuously meets the test-fluid parameters and water quality criteria. A portion of the total system volume shall be purged and replaced with fresh test-fluid continually.

6.1.2 *Single-Pass Test System*—A flow-through test system that passes the test-fluid through the specimens only once and is discarded.

6.2 *Specimen Holders*—Test specimens shall be supported to minimize or eliminate externally induced stresses. Specimens shall be allowed to freely expand bi-directionally.

7. Sampling, Test Specimens, and Test Units

7.1 *Sampling*—Select at random a sufficient amount of pipe to satisfy the specimen requirements of this test method. When testing as a system, randomly select a sufficient quantity of fittings.

7.2 *Test Specimen Size*—The PP piping specimens shall be 12 in. to 18 in. (300 mm to 460 mm) in length between fitting closures or between fitting joints. The specimens shall be nominal size 20 and be DR 7.4 when measured in accordance with Specification F2389. If this size/DR is not available for the material being tested, the diameter/DR pipe size with the lowest wall thickness commercially produced by the manufacturer shall be tested.

7.2.1 *Dimensions Measurement*—Measure and record the critical dimensions for pipe and fittings. For pipe, measure the average outside diameter and wall-thickness in accordance with Test Method D2122. For fittings, measure those dimensions critical to the function of the joint, as well as minimum body wall thickness.

7.3 *Testing as a System*—When testing PP pipe and related system components (such as fittings) as a system, the other components shall be attached to the PP pipe in the same manner as in actual service. For fittings, the particular fitting style shall be installed in accordance with the manufacturer's instructions or the ASTM specification when applicable.

7.4 *Testing as piping*—When testing PP piping, the joints and connections to and between specimens shall be representative of actual fittings used in the PP system, or shall be made with fittings made from a material inert to the effect of the test fluid.

7.5 *Minimum Required Test Units*—A minimum of six test units is required. A test unit is comprised of two or more individual time-to-failure data points at the same temperature and hoop stress condition. Statistical reliability of the analysis of the resultant data will be benefited by obtaining additional data points at each temperature/hoop stress condition.

7.5.1 *Test Unit Distribution*—Time-to-failure data points shall be obtained at 2 test hoop stresses at each of a minimum of 3 test temperatures for a minimum of 12 data points. Hoop stresses shall be separated by a least 80 psi (0.55 MPa).

7.5.2 *Test Temperature Selection*—Temperatures of 239 °F (115 °C), 221 °F (105 °C), and 203 °F (95 °C) have been utilized in prior testing of PP. Adjacent test temperatures shall be separated by at least 18 °F (10 °C). Other test temperatures may be used, but the maximum test temperature shall not exceed 239 °F (115 °C).

7.5.2.1 *Relationship of Internal Pressure to Hoop Stress*—The hoop stress in the pipe or tubing wall is calculated by the following expression, commonly known as the ISO equation:

$$\frac{2S}{P} = DR - 1 \qquad (1)$$

or

$$\frac{2S}{P} = \frac{D_o}{t} - 1 \qquad (2)$$

where:

S = stress in the circumferential or hoop direction, psi (MPa),
P = internal pressure, psig (kPa),
t = minimum wall thickness, in. (mm),
DR = dimension ratio, DR, and
D_o = average outside diameter, in. (mm).

8. Calibration and Standardization

8.1 *Measuring Equipment*—All measuring and testing equipment having an effect on the accuracy or validity of the calibrations or tests shall be calibrated or verified, or both, before being put into service

9. Test Fluid

9.1 *Internal Test Fluid*—The test fluid shall be reverse osmosis (RO) or deionized (DI) water prepared in accordance with 9.1.1.

9.1.1 *RO or DI Water Test-Fluid Preparation*—Test fluid prepared from RO or DI water shall have a pH in the range from 6.5 to 8.0 and contain 2.5 ppm to 5 ppm (milligrams per litre) of free-chlorine. The chosen pH shall be maintained to ±0.2 and the chosen free-chlorine concentration shall be maintained to ±0.2 ppm. The pH and free-chlorine concentration combination shall yield a minimum ORP of 825 mV for the test fluid, see Note 3. Testing shall be conducted with the same nominal pH and free-chlorine concentration for all test units.

NOTE 3—It is anticipated that use of RO or DI water may improve interlaboratory reproducibility; however, RO or DI water does not generally exist in real service. Since tap water (locally available potable water) quality can vary from location to location, and considering the international application of this test method, it seems prudent to utilize RO or DI water to minimize possible disparities of results obtained from laboratories in different geographical locations. Prior data obtained with test-fluid having an ORP of 750 mV or higher still provides a conservative extrapolation for potable-water conditions found in most areas of the United States.

9.1.2 *Test Fluid Temperature Control*—The test fluid entering each specimen shall be maintained to ±1.8 °F (±1 °C) of the test temperature.

9.1.3 *Pressure Control*—The pressure of the test fluid shall be maintained to ±3 psig (±20.69 kPa).

9.1.4 *Test Fluid Flow Rate*—The flow rate of the test fluid shall yield a minimum velocity of 0.12 fps (0.04 mps). For the nominal size 20 DR 7.4 pipe, this corresponds to a minimum flow rate of 0.10 gpm (0.36 LPM). The formula used to calculate the flow rates for other sizes and DRs is as follows:

$$Q = \frac{720\pi\left(\frac{id}{2}\right)^2 v}{231} \quad (3)$$

where:

Q = Minimum flow rate, gal/min (minimum flow necessary to achieve minimum velocity, rounded up to 2 decimal places)
id = measured inside diameter of the pipe, in.
v = flow velocity, ft/sec

9.2 *Test Fluid Instrument Accuracy:*

9.2.1 *pH*—The pH measurement and control instruments shall have an accuracy of 0.1 pH or better.

9.2.2 *Free-Chlorine*—Free-chlorine content measurement and control instruments shall have an accuracy of 0.1 ppm or better.

9.2.3 *ORP*—The ORP measurement and control instruments shall have an accuracy of ±10 mV or better.

10. External Environment

10.1 The external environment shall be air and shall be maintained at the target temperature of the test fluid temperature ±4.5 °F (±2.5 °C). Direct, forced-air heating of the specimens shall not be used.

11. Specimen Positioning

11.1 The specimens can be positioned vertically or horizontally. Horizontal positioning requires special attention to ensure that all entrapped air has been removed prior to starting the test. For vertically positioned specimens, the test fluid shall flow into the specimens from the lower end.

12. Procedure

12.1 Perform the test procedure in accordance with 12.2 – 12.4 for the test units specified in 7.4 with a test fluid as specified in Section 9.

12.2 After connecting the specimens to the flow-through apparatus, purge the specimens of all entrapped gas and start the flow of the test-fluid through the specimens at a temperature or pressure, or both, 40 % to 50 % less than the test condition. Over the next 1 h to 3 h, gradually increase the temperature and pressure of the test fluid to the test condition. When the test fluid reaches the test condition temperature, pressure, and flow rate, and the external environment has reached the test temperature in accordance with Section 10, record the start time.

12.3 Maintain the test condition until all of the specimens have failed. Any loss of fluid through the wall of the pipe or tubing or assembly constitutes a failure. Record the time-to-failure for each failed specimen within ±1 % of the test time for the specimen. When multiple specimens are connected end-to-end, remove each failed specimen and continue the test until all remaining specimens at the conditions have failed.

12.4 Record the time in hours and a description for each failure. The description of each failure shall include: linear location from flow inlet, circumferential position, and initiation point (inside or outside of tube). For accurate test life extrapolation, all of the failures must be the same type. Mixed mode failures and failures initiated from the outside of the tube shall not be used for data analysis, see Note 4.

NOTE 4—Numerous failures occurring predominantly in approximately the same position on the tube circumference should be examined carefully. When there is an indication that the failures are attributable to the design or operation of the test, these values should be discarded unless it can be demonstrated that the testing provided a more conservative estimate of the oxidative resistance.

13. Calculation

13.1 *Regression Analysis*—Perform a multiple linear regression on the Stage III time-to-failure data in accordance with ISO 9080. The regression curve at each temperature shall have a negative slope. The test of fit (probability of the F value exceeding 0.05) shall be calculated in accordance with ISO 9080.

13.1.1 The extrapolations in 13.2 and 13.3 are applicable for products with a nominal wall thickness that meets or exceeds the nominal wall thickness of the tested specimens.

13.2 *Time-to-Failure Extrapolations*—Using the regression model from 13.1, calculate the estimated time-to-failure at a hoop stress corresponding to a sustained internal pressure and each temperature in accordance with Table 1.

NOTE 5—Calculations of the estimated time-to-failure may also be made at other temperatures and SDRs up to the highest rated temperature and across the SDR range of the specific product line.

NOTE 6—It may be convenient to also report the extrapolated time-to-failure in years by dividing hours by 8760.

13.3 *Application of Miner's Rule*—Calculate the estimated time to-failure for a hoop stress corresponding to a sustained internal pressure and exposure conditions in accordance with Table 2 in accordance with ISO 13760. An example is shown in X1.2.

14. Report

14.1 *Report Content*—Report the minimum information as required in 14.2 – 14.9.

14.2 Laboratory name and location and starting and ending dates of the test.

14.3 Chlorine source (that is, chlorine gas, hypochlorite, and so forth)

14.4 Identification of the PP pipe in the report shall include: pipe nominal size and DR or wall thickness specification; average outside diameter and minimum wall thickness of each specimen; pipe manufacturer's name, trade designation and pipe lot number (if applicable); resin manufacturer's name, compound designation, and lot designation (for in-plant compounded materials, resin manufacturer's name may be omitted).

14.5 Identification of fitting(s) tested with the PP pipe (if applicable) shall include: manufacturer's name and model or designation, fitting type, material, and ASTM standard designation (if applicable).

TABLE 1 Extrapolation Conditions at Constant Temperature

DR	Pressure, psig (kPa)	Temperature, °F (°C)
9 or lower	80 (550)	180 (82), 140 (60), 73 (23)
Any DR[A]	160 (1100)	73 (23)

[A] SDR 11 and higher pipe, tubing, and systems are extrapolated for cold water applications only in Table 1.

TABLE 2 Exposure Conditions for Application of Miner's Rule

DR	Pressure, psig (kPa)	% of the total time at 140 °F (60 °C)	% of the total time at 73 °F (23 °C)
9 or lower	80 (550)	50	50
9 or lower	80 (550)	25	75

14.6 All test conditions, including: test fluid temperature/internal pressure combinations; specimen external air temperature; test fluid free-chlorine concentration and pH; test fluid ORP; water type (RO or DI); flow rate; and specimen position (horizontal or vertical). Where applicable, report the minimum, maximum, and average values for each parameter.

14.7 A table of the test temperatures, hoop stresses, and failure times for all specimens tested.

14.8 A description of each failure in accordance with 12.4.

14.9 A summary of the regression analysis including: coefficients; test-of-fit results; estimated times-to-failure as specified in 13.2, Time-to-failure extrapolations and 13.3, Application of Miner's Rule.

15. Precision and Bias

15.1 *Precision*—It is not feasible to specify the interlaboratory precision at this time due to the limited number of laboratories and test stations available. A separate work item will be established to conduct the necessary round-robin testing. It is expected that the precision of this method will be essentially the same as F2023.

15.2 *Bias*—No information can be presented on the bias of this test method because no material having an accepted reference value is available.

16. Keywords

16.1 chlorine; DHWR; domestic hot water recirculation; hot-and-cold water distribution system; oxidation; oxidative; polypropylene; PP-R; PP-RCT; recirculation