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Standard Test Method for Time-to-Failure of Plastic Piping Systems and Components Under Constant Internal Pressure With Flow[1]

This standard is issued under the fixed designation F948; 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 covers the determination of the time-to-failure of plastic piping products under constant internal pressure and flow.

1.2 This test method provides a method of characterizing plastics in the form of pipe, components, and systems under any reasonable combination of internal and external temperatures and environments, under the procedures described.

1.3 This test method can be used to characterize the tested plastic materials or products, or both, on the basis of pressure-, or stress-rupture data developed under the conditions prescribed.

1.4 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.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D543 Practices for Evaluating the Resistance of Plastics to Chemical Reagents

D2122 Test Method for Determining Dimensions of Thermoplastic Pipe and Fittings

D2837 Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials or Pressure Design Basis for Thermoplastic Pipe Products

D2992 Practice for Obtaining Hydrostatic or Pressure Design Basis for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe and Fittings

D3567 Practice for Determining Dimensions of "Fiberglass" (Glass-Fiber-Reinforced Thermosetting Resin) Pipe and Fittings

E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

2.2 *PPI Documents:*

TR-2 Policies and Procedures for the Listing of Thermoplastic Pipe, Fittings, and Fixture Materials When Evaluated Under Constant Internal Pressure With Flow[3]

TR-3 Policies and Procedures for Developing Recommended Hydrostatic Design Stresses for Thermoplastic Pipe Materials[3]

3. Terminology

3.1 *Definitions:*

3.1.1 *failure*—bursting, cracking, splitting, or weeping (seepage of test fluid through the wall of the product) during the test, which results in the inability of the specimen to maintain pressure or contain the internal test fluid, shall constitute failure of the test specimen. Failure may sometimes occur by ballooning, an excessive extension leading to structural failure. When failure occurs by ballooning the degree of distension should be recorded. Assemblies may also fail to joint leakage or separation.

NOTE 1—Overall distension, which results from creep caused by long-term stress, is not considered to be a ballooning failure.

3.1.2 *hoop stress*—the tensile stress in the wall of the piping product in the circumferential direction due to internal pressure. Units will be reported as pounds per square inch (psi) or mega pascals (MPa). Hoop stress will be calculated by the following ISO equation:

$$S = P\,(D - t)/2t$$

where:

S = hoop stress, psi (MPa),

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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.

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

D = average outside diameter, in. (mm),
P = internal pressure, psig (MPag), and
t = mimimum wall thickness in. (mm).

NOTE 2—Hoop stress should only be determined on straight hollow cylindrical specimens. Products of more complex shape may be evaluated by Option 2 of Appendix X1 based on pressure.

3.1.3 *make-up fluid*—an exchange of internal fluid with fresh fluid at a minimum rate of 10 % of the total system volume per week.

3.1.4 *maximum internal surface temperature*—that temperature attained when increased fluid velocity results in no further increase in the outside surface temperature of the specimen (see X2.7).

3.1.5 *pressure*—the force per unit area exerted by the test fluid in the piping product. Units will be reported as pounds per square inch gage (psig) or mega pascals gage (MPag).

3.1.6 *test assembly*—components (such as, pipe, fittings, valves, etc.) tested separately or together in an array that may simulate an actual field system that might include joints, fusions, plastic-to-metal transitions, etc.

4. Summary of Test Method

4.1 This test method consists of exposing specimens of extruded, molded, or otherwise manufactured pipe or components (such as fittings, valves, assemblies, etc.) to a constant internal pressure by a flowing test fluid of controlled temperature and composition, while in a controlled external environment. Time-to-failure and specimen surface temperature should be measured during exposure under the test conditions. Unless otherwise specified the internal fluid shall be water and the external environment will be air.

5. Significance and Use

5.1 The data obtained by this test method are useful for establishing pressure, or hoop stress where applicable, versus failure-time relationships, under independently controlled internal and external environments that simulate actual anticipated product end-use conditions, from which the design basis (DB) for piping products or materials, or both, can be determined. (Refer to Test Method D2837 and Practice D2992, and Appendix X1 of this test method.)

NOTE 3—Reference to design basis (DB) in this test method refers to the hydrostatic design basis (HDB) for material in straight hollow cylindrical shapes where hoop stress can be easily calculated, or is based on applied pressure design basis (PDB) for complex-shaped products or systems where complex stress fields seriously prohibit the use of hoop stress.

5.2 In order to characterize plastics as piping products, it is necessary to establish the stress-to-rupture-time, or pressure-to-rupture-time relationships over two or more logarithmic decades of time (hours) within controlled environmental parameters. Because of the nature of the test and specimens employed, no single line can adequately represent the data. Therefore, the confidence limits should be established.

5.3 Results obtained at one set of environmental conditions should not be used for other conditions, except that higher temperature data can be used for a design basis assignment for lower application temperatures, provided that it can be demonstrated that the application conditions present a less stringent environment. The design basis should be determined for each specific plastic material and each different set of environmental constraints. Design and processing can significantly affect the long-term performance of piping products, and therefore should be taken into consideration during any evaluation (see Appendix X2).

5.4 Specimens used must be representative of the piping product or material under evaluation (see Appendix X2).

6. Apparatus

6.1 *Constant-Temperature System:*

6.1.1 *Controlling the Internal Environment of Test Specimens*—Any system that will ensure that the test fluid entering and exiting the test specimen is maintained at a constant temperature within ± 3.6°F (±2°C) throughout the duration of the test.

6.1.2 *Controlling the External Environment of Test Specimens*—Any system that will ensure constant external environment temperature within ±3.6°F (±2°C) throughout the duration of the test.

6.2 *Dynamic Flowing Pressure System*—Any device that is capable of continuously applying a constant internal pressure within the tolerance limits defined in Table 1, while allowing a continuous flow through the test specimens. The flow rate should be substantial enough to control the internal temperature of each test specimen. The device shall be capable of reaching the test pressures without exceeding it, and holding the pressures within the tolerances listed in Table 1 for the duration of the test.

NOTE 4—Pressure variations from pumps may exceed the tolerance limits. (See X2.6.)

6.3 *Pressure Gage*—A pressure measuring instrument capable of determining the internal pressure of the test specimen(s) within the limits as required in Table 1.

6.4 *Timing Device*—Any timing device or system capable of determining the time-to-failure for each test specimen, within the tolerances listed in Table 1.

6.5 *Specimen Holder*—Any device that will support the specimens, but will minimize externally induced stresses. Provisions shall be made to allow for normal bidirectional thermal expansion of the test specimen.

6.6 *Feed-and-Bleed System*—Provisions shall be made to introduce fresh make-up fluid to the system while bleeding off an equivalent amount necessary to maintain a constant volume and ensure constant composition of the test fluid. This system should be designed to maintain composition of the internal fluid within prescribed limits.

TABLE 1 Tolerances for Testing Thermoplastic Piping Products

Test Periods, h	Pressure, %	Time, %
0 to 10	±0.5	±0.5
10 to 100	±0.5	±1.0
100+	±1.0	±2.0

6.7 *Other Provisions*—Additional provisions may be necessary to maintain constant composition.

6.8 *Flow Control*—Provisions shall be made to ensure that the internal fluid velocity shall be adequate to ensure constant internal temperature in the specimen within ±3.6°F (±2°C). In the special case of hot water inside/ambient air outside, provision shall be made to ensure maximum internal surface temperature of the specimen within ±3.6°F (±2°C).

7. Test Specimens

7.1 *Material*—Material evaluation shall be done on cylindrical test specimens molded or formed by the same process as the actual product. Unless otherwise specified the part shall meet the specimen requirements as follows:

7.1.1 *Injection Molded*—The test specimens shall be injection molded tubes with as uniform a wall as technically possible. The mold shall be side-gated so that a bond line is created lengthwise along the tubular test specimens (see Note 5). The working exposed length of the specimen in the test shall have a minimum length to actual outside diameter ratio of 5 to 1.

NOTE 5—The PPI Hydrostatic Stress Board is currently evaluating the question of side versus end gating as part of a broad study of the forecasting of the long-term strength of fittings.

7.1.2 *Extrusion*—The specimen length between end closures shall be not less than 5 times the nominal outside diameter of the pipe, but in no case less than 12 in. (300 mm).

7.1.3 *Others*—For manufacturing processes other than those specified, straight hollow cylindrical shapes produced by the process should be used as specimens for evaluating the material. Restriction of 7.1.2 should apply.

7.2 *End-Use Products*—Actual commercial designs simulating end-use products shall be representative of the final product design and manufacturing process (see Appendix X2).

7.3 *Systems and Assemblies*—System or subsystem designs that include joints or other assembly techniques which represent field installations, or both, may be tested.

7.4 *Measurements*—Dimensions shall be determined in accordance with Test Method D2122 or Practice D3567, where applicable.

8. Conditioning

8.1 If the external environment is gaseous, test specimens shall be conditioned in the external air or gaseous environment for a minimum of 16 h before pressurizing the internal test fluid. If the external environment is a liquid, test specimens shall be conditioned for a minimum of 1 h. This conditioning period may be concurrent with internal conditioning using flowing internal test fluid. Refer to Table 2.

TABLE 2 Minimum Conditioning Period

External Fluid	Internal Fluid	Minimum External Environment Exposure, h	Minimum Internal Flowing, h
Gas	Gas	16	16
Gas	Liquid	16	1
Liquid	Gas	1	16
Liquid	Liquid	1	1

8.2 The internal test fluid shall be circulated through the test specimens for a minimum of 1 h if liquid, or 16 h if gaseous, before applying test pressure. Refer to Table 2.

9. Procedure

9.1 Attach the specimens or assemblies to the system supported in a manner that will minimize externally induced stresses and minimize entrapment of gas in the specimen when the internal fluid is a liquid.

9.2 After conditioning the specimens as specified in Section 8, adjust the pressure to produce the desired loading. Apply the pressure to the specimens and make sure the timing devices have started after reaching the assigned pressure. Pressures should be preset prior to loading test specimens in order to avoid overstressing the specimens during pressure setting procedure.

9.3 Periodically, measure the surface temperature of each test specimen (see X2.7) and the air temperature near the test specimen's surface.

9.3.1 Any failure occurring within one pipe diameter of the joining system of the test assembly to test apparatus should be examined carefully. If there is any reason to believe that the failure was attributable to the joining system, this data point should not be used in the regression equation computations.

9.3.2 All data must be reported, whether employed in the regression analysis or not. Widely scattered failures may be indicative of performance to be expected in the field. If circumstances can be determined for inconsistent test performance, the reason should be so noted with the failure time.

10. Report

10.1 Report the following information:

10.1.1 Complete identification of the sample, including material type, source, manufacturer's name and code number, and previous significant history, if any.

10.1.2 Specimen dimensions, including nominal size and, when applicable, average and minimum wall thickness, average outside diameter and length to diameter ratio.

10.1.3 A sketch of the test specimen shall be included in the report.

10.1.4 Fluid temperatures inside and outside the specimen.

10.1.4.1 *For Water Inside/Ambient Air Outside*—Report fluid temperatures entering and leaving the specimen, air temperature around the specimens, minimum external surface temperature of the specimens, and method used to measure surface temperature of the specimens.

10.1.5 Test environments inside and outside the specimen.

10.1.6 A table of pressures or stresses, or both, and the respective time-to-failure in hours for all the specimens tested.

10.1.6.1 In those cases where pressure variations could affect the life performance, pressure variations should be reported (see X2.6).

10.1.7 The nature of the failures in accordance with 3.1.1. In the case of test assemblies, the failure type and location (such as, fitting, joint, seal, etc.) must be included.

10.1.8 Any unusual behavior observed in the tests. Any change in color, surface texture, or other change in appearance that may be the result of a physical, chemical, or environmental effect must be reported, whether or not such change played a role in the failure of the part.

10.1.9 Dates of test.

10.1.10 Name of laboratory and signature of the supervisor of the tests.

11. Precision and Bias

11.1 *Precision*—This test method has produced replicate failure times over a wide stress level for acetal (POM) resins using an injection molded tubular specimen. The two sigma percent precision was 49 %, using the analytical procedure in Practice E177. This precision is based on one laboratory, several test assemblies, and three different acetal resins.

11.1.1 The two sigma precision of the extrapolated 100 000 and 50 year stress values for a single acetal resin, triplicated by a single laboratory was 15 %.

11.2 *Bias*—Data obtained using this test method are believed to be reliable since accepted techniques of analysis are used. However, since no referee method is available, no bias statement can be made.

12. Keywords

12.1 constant flow; constant internal pressure; plastic pipe; pressure pipe; time to failure

APPENDIXES

(Nonmandatory Information)

X1. DATA ANALYSIS

X1.1 Option 1—Hoop Stress Versus Time-to-Failure

X1.1.1 The treatment of hoop stress data is well established and has been defined in Test Method D2837 for thermoplastic materials and Practice D2992 for reinforced thermosetting materials. The application of data developed by this test method, to treatment by either Test Method D2837 or Practice D2992, presents no conflict with the theory or practice of either method. It should, however, be pointed out in the report that the data were developed by the flowing method.

X1.1.2 Hoop stress is a more convenient parameter to use when attempting to predict long-term hydrostatic strength of a material. Its use reduces scatter in the data by compensating for varying dimensions in the test specimens. It effectively normalizes pressure for variations in specimen geometry, and reduces the variable to a material parameter. For this particular reason it has been widely used for evaluating the long-term hydrostatic properties of plastics materials. Essentially, once a value for hydrostatic design basis has been determined for a particular compound, that value can be used to effectively predict the long-term working pressure of tubular products by compensating for the various product geometries. See Table X1.1.

TABLE X1.1 Pressure Design Basis Categories

Minimum LTHP Values		Nominal Categories	
psig	MPag	psig	MPag
95	0.65	100	0.69
120	0.83	125	0.86
150	1.03	160	1.10
190	1.31	200	1.38
240	1.65	250	1.72
300	2.07	315	2.17
380	2.62	400	2.76
480	3.31	500	3.45
600	4.14	630	4.34
760	5.24	800	5.52

X1.1.3 The use of hoop stress derived from the equation given in 3.1.2 has limitations when applied to test specimens which are (*a*) other than pipe and couplings, (*b*) have varying wall thickness by design, etc., or (*c*) have significant or unusual temperature gradient through the wall.

X1.1.4 Although the test is performed hydrostatically, the application of long-term hydrostatic hoop stress is not limited to establishing the performance of pressure products only. Since hoop stress is a tensile stress, and the mode of failure is a function of creep, the data is also useful in determining the long-term structural capabilities of a material. Such information is useful and often not available, when attempting to establish long-term performance of simple structural members under tensile stress.

X1.2 Option 2—Pressure Versus Time-to-Failure

X1.2.1 The use of pressure as the independent variable extends the application of the method to the prediction of service life for many products of complex geometries that do not permit the calculation of hoop stress. The method is analogous to the method delineated in Test Method D2837, except that log gage pressure (psig) shall be used in place of log hoop stress in the calculation. The reader is advised to become familiar with Test Method D2837 before proceeding.

X1.2.2 With the exception of the calculation of hoop stress, all parts of Test Method D2837 are applicable to the evaluation of pressure components. However, the use of pressure necessitates a change in some of the following terminology:

X1.2.2.1 *long-term hydrostatic pressure (LTHP)*—the estimated internal pressure of the piping product that, when applied continuously, will cause failure of the product at

100 000 h. This is the intercept of the log pressure versus log rupture time regression line with the 100 000 h coordinate.

X1.2.2.2 *pressure design basis (PDB)*—one of a series of established pressure values for a plastic piping product obtained by categorizing the LTHP using the same method of categorizing the LTHS in Test Method D2837 (see Table X1.1).

X1.2.2.3 *service design factor*—a number less than 1.00 (which takes into consideration all the variables and degree of safety involved in a plastic piping installation) that is multiplied by the PDB to give the pressure rating (PR) of the product.

X1.2.2.4 *pressure rating (PR)*—the estimated maximum gage pressure that the test fluid in the product can exert continuously with a high degree of certainty that failure of the product will not occur.

X2. OTHER PERFORMANCE CONSIDERATION

X2.1 The long-term performance of plastic components is affected by many parameters; the most prominent being the level of stress, the duration of imposed stress, and the temperature of the material during exposure. This procedure addresses these most critical parameters. It should, however, be noted that many other factors can affect the long-term behavior of polymeric components.

X2.2 *Product Design*—The hydrostatic design stress recommended by the Plastics Pipe Institute (PPI) is used to rate the long-term performance of materials. In the case of materials to be used for injection molding of fittings or other pressure components, PPI recommends a molded tubular design (refer to PPI TR-3) that permits the evaluation of materials on a similar basis. The design is a simple tube, that permits the calculation of hoop stress and allows the evaluation of a molded component with certain "controlled" defects that would inherently be found in an injection molded product, that is, gates, knit-lines, material orientation, parting lines, etc. Such data is designed for comparative evaluations of materials and should not be directly applied to other more complex designs without first evaluating the long-term effects of the new design.

X2.2.1 Any design more complex than a simple tube, may prohibit the use of hoop stress due to the complexity of the stress fields generated by the design. Serious considerations should be given to product design. Notches, sharp corners, and sharp transition from thick to thin sections should be avoided or at least minimized wherever possible. Attention should be directed to gate and knit-line location.

X2.2.2 If the original testing had been performed on prototype parts or parts manufactured on unoptimized tooling, a retest should be performed on actual production components to ensure that design variations have not significantly affected the estimated service life of the product. Seemingly subtle variations in tooling or product design can alter the product's long-term performance.

X2.3 *Environmental Effects*—All materials can be affected by their environment. Plastic materials are no different. The common method to determine a plastic's susceptibility to a particular environment or media is to evaluate the material by Test Method D543 for chemical resistance. This test method is applicable for determining long-term effects on a material's short-term properties, but does not adequately determine the material's long-term performance in service. Environments that result in little to no effect by Test Method D543 have been found to significantly reduce product service life. For this reason, serious considerations should be given when defining the environments for the test. Environments should be selected that best represent or simulate actual environmental conditions in the field. Where conditions vary in the field, worse-case conditions should prevail. The data from the test method only measures mechanical performance of the pipe or device being tested. It does not measure the long-term chemical stability of the plastic.

X2.4 *Processing*—Although the service life of a product depends primarily on the product design, material choice, and the quality of the manufactured product, subtle processing changes can significantly affect long-term performance with no obvious changes in appearance or short-term properties. Variations in processing or mold temperatures, alteration of injection pressure, rates, or dwell time can result in variation in orientation, packing, knit-line strength, and, for crystalline or multiphase polymer systems, change in morphology, all of which ultimately relate to long-term performance of the product. An engineering study should be performed that can define the limits of processing variables in order to ensure long-term product quality. In any case, processing changes should not be made without regard to the potential effect on long-term performance.

X2.5 *Wall Thickness*—It may be construed that wall thickness is not a significant consideration in regard to long-term performance of polymeric components (other than the obvious effect on stress). However, wall thickness can, in some instances, significantly affect the outcome of a product's service life. Skin-effects can result in a significant improvement in a material's long-term performance; therefore using a thin wall where the skin carries a proportionately higher share of the load could improve the extrapolation for the material. On the other hand, in the instance where long-term strength may be dependent upon the material's ability to resist chemical transport, such as in the case of plasticization through liquid or gaseous permeation, thicker walls could provide improved service life. Therefore serious consideration should be given to the effect of wall thickness with regard to a particular application. Also, when scaling-up (or down) a design, a study should be performed to ensure that alteration of wall thickness will not significantly affect the expected long-term performance of the larger (or smaller) designs.

X2.6 *Pressure Variations*—Pressure variations generated by reciprocating piston pumps may exceed the tolerance limits. These variations should be minimized, as the resulting fatigue may affect the results. At the start of the test, and when samples are added to or removed from the system, it is advisable to check the dynamic pressure variations and period with an oscilloscope and transducer.

X2.7 *Surface Temperature Measurement*—Infrared thermometry has been shown to be a rapid, reliable method for measuring the surface temperature of injection molded tubes undergoing this test with 180°F water circulating inside and ambient air outside. By contrast, contact measurements using a bimetallic pyrometer were unreliable and not reproducible. Other methods of measurement may be satisfactory.