Designation: D 2837 – 98a

An American National Standard

Standard Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials[1]

This standard is issued under the fixed designation D 2837; 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 a procedure for obtaining a hydrostatic design basis for thermoplastic pipe materials, by evaluating stress rupture test data derived from testing pipe made from the subject material. The method is applicable to all known types of thermoplastic pipe and for any practical temperature and medium.

1.2 Unless the data approximate a straight line, when calculated using log-log coordinates, it is not possible to assign a hydrostatic design basis to the material. Data that exhibit high scatter or a "knee" give low (that is, conservative) extrapolated values when evaluated. In addition, the lower confidence level limits are not met and the data are classed as unsuitable.

1.3 The values stated in inch-pound units are to be regarded as the standard.

NOTE 1—Over 1200 sets of data, obtained with thermoplastic pipe and piping assemblies tested with water, natural gas, and compressed air, have been analyzed. None of the compounds in the lists of Recommended Hydrostatic Strengths and Design Stresses for Thermoplastic Pipe and Fittings Compounds in PPI Technical Report TR4, issued at intervals for over 12 years by the Plastics Pipe Institute, exhibit knee-type plots, that is, deviate from a straight line in such a manner that a marked drop occurs in stress at some time when plotted on equiscalar log-log coordinates. Data have been obtained for test periods over 120 000 h. It might be noted that some thermoplastic compounds that are not suitable or recommended for piping components do exhibit knee-type plots at 23°C (73°F); in these cases, very low results are obtained when the data are analyzed by this test method. Futher information on piping compounds may be found in the references at the end of this test method.

1.4 The experimental procedure to obtain individual data points shall be as described in Test Method D 1598, which forms a part of this test method. When any part of this test method is not in agreement with Test Method D 1598, the provisions of this test method shall control.

1.5 General references are included at the end of this test method.

1.6 *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:*

D 1598 Test Method for Time-to-Failure of Plastic Pipe Under Constant Internal Pressure[2]

E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications[3]

3. Terminology

3.1 *Definitions:*

3.1.1 *pressure*—the force per unit area exerted by the medium in the pipe.

3.1.2 *hoop stress*—the tensile stress in the wall of the pipe in the circumferential orientation due to internal hydrostatic pressure.

3.1.3 The following equations shall be used for the relation between stress and pressure:

$$S = P(D - t)/2t \text{ for outside diameter controlled pipe} \quad (1)$$

or

$$S = P(d + t)/2t \text{ for inside diameter controlled pipe} \quad (2)$$

where:

S = stress,
P = pressure,
D = average outside diameter,
d = average inside diameter, and
t = minimum wall thickness.

3.1.4 *failure*— bursting, cracking, splitting, or weeping (seepage of liquid) of the pipe during test.

3.1.5 *long-term hydrostatic strength (LTHS)*— the estimated tensile stress in the wall of the pipe in the circumferential orientation that when applied continuously will cause failure of the pipe at 100 000 h. This is the intercept of the stress regression line with the 100 000-h coordinate.

3.1.6 *hydrostatic design basis (HDB)*—one of a series of established stress values for a compound. It is obtained by categorizing the LTHS in accordance with Table 1.

3.1.7 *service (design) factor*—a number less than 1.00 (which takes into consideration all the variables and degree of

[1] This test method is under the jurisdiction of ASTM Committee F-17 on Plastics Piping Systems and is the direct responsibility of Subcommittee F17.40 on Test Methods.

Current edition approved December 10, 1998. Published March 1999. Originally published as D 2837 – 69. Last previous edition D 2837 – 98.

[2] *Annual Book of ASTM Standards*, Vol 08.04.

[3] *Annual Book of ASTM Standards*, Vol 14.02.

TABLE 1 Hydrostatic Design Basis Categories

NOTE 1—The LTHS is determined to the nearest 10 psi. Rounding procedures in Practice E 29 should be followed.

Range of Calculated LTHS Values		Hydrostatic Design Basis	
psi	(MPa)	psi	(MPa)
190 to < 240	(1.31 to < 1.65)	200	(1.38)
240 to < 300	(1.65 to < 2.07)	250	(1.72)
300 to < 380	(2.07 to < 2.62)	315	(2.17)
380 to < 480	(2.62 to < 3.31)	400	(2.76)
480 to < 600	(3.31 to < 4.14)	500	(3.45)
600 to < 760	(4.14 to < 5.24)	630	(4.34)
760 to < 960	(5.24 to < 6.62)	800	(5.52)
960 to <1200	(6.62 to < 8.27)	1000	(6.89)
1200 to <1530	(8.27 to <10.55)	1250	(8.62)
1530 to <1920	(10.55 to <13.24)	1600	(11.03)
1920 to <2400	(13.24 to <16.55)	2000	(13.79)
2400 to <3020	(16.55 to <20.82)	2500	(17.24)
3020 to <3830	(20.82 to <26.41)	3150	(21.72)
3830 to <4800	(26.41 to <33.09)	4000	(27.58)
4800 to <6040	(33.09 to <41.62)	5000	(34.47)
6040 to <6810	(41.62 to <46.92)	6300	(43.41)
6810 to <7920	(46.92 to <54.62)	7100	(48.92)

safety involved in a thermoplastic pressure piping installation) which is multiplied by the HDB to give the HDS.

3.1.8 *hydrostatic design stress (HDS)*—the estimated maximum tensile stress in the wall of the pipe in the circumferential orientation due to internal hydrostatic pressure that can be applied continuously with a high degree of certainty that failure of the pipe will not occur.

3.1.9 *pressure rating (PR)*—the estimated maximum pressure that the medium in the pipe can exert continuously with a high degree of certainty that failure of the pipe will not occur.

3.1.9.1 The PR and HDS are related by the equations given in 3.3.

4. Significance and Use

4.1 The procedure for estimating long-term hydrostatic strength is essentially an extrapolation with respect to time of a stress-time regression line based on data obtained in accordance with Test Method D 1598. Stress-failure time plots are obtained for the selected temperature and environment: the extrapolation is made in such a manner that the long-term hydrostatic strength is estimated for these conditions.

NOTE 2—Test temperatures should preferably be selected from the following: 40°C; 50°C; 60°C; 80°C; 100°C. It is strongly recommended that data also be generated at 23°C for comparative purposes.

4.2 The hydrostatic design basis is determined by considering the following items and evaluating them in accordance with 5.4.

4.2.1 Long-term hydrostatic strength at 100 000 h,

4.2.2 Long-term hydrostatic strength at 50 years, and

4.2.3 Stress that will give 5 % expansion at 100 000 h.

4.2.4 The intent is to make allowance for the basic stress-strain characteristics of the material, as they relate to time.

4.3 Results obtained at one temperature cannot, with any certainty, be used to estimate values for other temperatures. Therefore, it is essential that hydrostatic design bases be determined for each specific kind and type of plastic compound and each temperature. Estimates of long-term strengths of materials can be made for a specific temperature provided that calculated values, based on experimental data, are available for temperatures both above and below the temperature of interest.

4.4 Hydrostatic design stresses are obtained by multiplying the hydrostatic design basis values by a service (design) factor.

4.5 Pressure ratings for pipe may be calculated from the hydrostatic design stress (HDS) value for the specific material used to make the pipe, and its dimensions using the equations in 3.3.

5. Procedure

5.1 *General*—Generated data in accordance with Test Method D 1598.

5.2 *Stress Rupture*—Obtain the data required for 4.2.1 and 4.2.2 as follows:

5.2.1 Obtain a minimum of 18 failure stress-time points for each environment. Distribute these data points as follows:

Hours	Failure Points
<1000	At least 6
10 to 1000	At least 3
1000 to 6000	At least 3
After 6000	At least 3
After 10 000	At least 1

NOTE 3—When the long-term stress regression line of a compound is known, this method may be used, using fewer points and shorter times, to confirm material characteristics, or to evaluate minor process or formulation changes. See also PPI TR3, Policies and Procedures for Developing Recommended Hydrostatic Design Stresses for Thermoplastic Pipe Materials.

5.2.2 Analyze the test results by using, for each specimen, the logarithm of the stress in psi and the logarithm of the time-to-failure in hours as described in Appendix X1 (Note 4). Calculate the strength at 100 000 h. Include as failures at the conclusion of the test those specimens which have not failed after being under test for more than 10 000 h if they increase the value of the extrapolated strength. Accomplish this by first obtaining the linear log-log regression equation for only the specimens that failed, by the method of least squares as described in Appendix X1. Then use the stress in psi for each specimen that has been under test for more than 10 000 h, and that has not failed, with this regression equation to calculate the time in hours. If this time is less than the hours the specimen has been under test, then use the point. Determine the final line for extrapolation by the method of least squares using the failure points along with those non-failure points selected by the method described above. Unless it can be demonstrated that they are part of the same regression line, do not use failure points for stresses that have failure times less than 10 h. Include failure points excluded from the calculation by this operation in the report, and identify them as being in this category. Refer also to Appendix X8.

NOTE 4—It should be noted that contrary to the custom in mathematics, it has been the practice of those testing plastics pipe to plot the independent variable (stress) on the vertical (y) axis and the dependent variable (time-to-failure) on the horizontal (x) axis. The procedure in Appendix X1 treats stress as an independent variable.

5.2.3 Determine the suitability of the data for use in determining the long-term hydrostatic strength and hydrostatic design basis of plastic pipe as follows:

5.2.3.1 Extrapolate the data by the method given in Appendix X1, to 100 000 h and 50 years, and record the extrapolated stress values (4.2.1 and 4.2.2), and

5.2.3.2 Calculate, by the method given in Appendix X2, the lower confidence value of stress at 100 000 h.

5.2.3.3 If the lower confidence value at 100 000 h differs from the extrapolated LTHS value by more than 15 % of the latter, or M in Appendix X2 is zero or negative, or b in the equation $h = a + bf$ in Appendix X1 is positive, consider the data unsuitable.

5.3 *Circumferential Expansion*—Obtain the data required for 4.2.3 as follows:

5.3.1 Initially test at least three specimens at a stress of 50 % of the long-term hydrostatic strength determined in 5.2.3.1 until the circumferential expansion exceeds 5 % or for 2000 h, whichever occurs first. Measure the expansion of the circumference in the center of that section of the pipe specimen that is under test to the nearest 0.02 mm (0.001 in.) periodically (Note 5) during the test, unless the expansion at some other point is greater, in which case measure the section with the maximum expansion. Calculate the changes in circumference for each specimen as a percentage of the initial outside circumference. Calculate the expansion at 100 000 h for each specimen by the method given in Appendix X3 or by the plotting technique described in 5.3.3. If the calculated expansion for one or more of the specimens tested exceeds 5 %, then use the hydrostatic stress as determined from circumferential expansion measurements as the stress value to be categorized to establish the hydrostatic design basis.

NOTE 5—It is suggested that these measurements be made once every 24 h during the first 5 days, once every 3 days during the next 6 days, and once a week thereafter. The periods shall be selected on the basis of past experience with the type of pipe so that they will be reasonably distributed to obtain a good plot.

5.3.2 The stresses and distribution of specimens used to determine hydrostatic stress from circumferential expansion measurements shall be as follows:

Approximate Percent of Long-Term Hydrostatic Strength (See 5.2)	Minimum Number of Specimens
20	3
30	3
40	3
50	3
60	3

Subject the specimens to test until the circumferential expansion exceeds 5 % or for 2000 h, whichever occurs first.

5.3.3 The results may be calculated by the methods given in Appendix X3 and Appendix X4 or plotted by the following procedures. Plot the percent changes in circumference against time in hours on log-log graph paper. Draw a straight line by the method of least squares, with time as the independent variable as described in Appendix X3. Calculate the expansion of the circumference in percent at 100 000 h for each specimen by the equation from Appendix X3:

$$c = a' + 5.00\, b' \quad (3)$$

Do not use extrapolations of curves for specimens that expand more than 5 % in less than 1000 h. Plot the corresponding expansion-stress points from the 100 000 h intercept on log-log graph paper and draw a line representative of these points by the method of least squares with stress as the independent variable as described in Appendix X4.

5.3.4 Calculate the stress corresponding to a circumferential expansion of 5.00 % in accordance with 5.3.3 and Appendix X4. The stress is the antilog of r in the equation $c = a'' + b'' r$ in Appendix X4. Use the values for a'' and b'' as calculated in Appendix X4 and 0.6990 for c. This stress may be obtained by calculation or read from the circumferential expansion-stress plot obtained in 5.3.3. In cases of disagreement, use the calculation procedure.

5.4 *Hydrostatic Design Basis*—The procedure for determining the HDB shall be as follows (see also Appendix X7):

5.4.1 Calculate the hydrostatic strength at 100 000 h (LTHS) in accordance with 5.2.

5.4.2 Calculate the hydrostatic strength at 50 years in accordance with 5.2.3.1.

5.4.3 Estimate the long-term hydrostatic strength using expansion test data and in accordance with 5.3.

NOTE 6—For all the presently used stress rated thermoplastic pipe materials in North America the 5 % expansion strengths are not the limiting factor. Therefore, this measurement is not required for such materials.

5.4.4 Determine the hydrostatic design basis (HDB) by categorizing, in accordance with Table 1, the applicable hydrostatic strength value as specified below:

5.4.4.1 Use the LTHS value (5.4.1) if it is less than 125 % of the 50-year value (5.4.2), and less than the expansion strength value (5.4.3).

5.4.4.2 Use the 50-year value if it is less than 80 % of the LTHS value, and less than the expansion strength value.

5.4.4.3 Use the expansion strength value if it is less than the LTHS and 50-year values.

5.5 *Hydrostatic Design Stress*—Obtain the hydrostatic design stress by multiplying the hydrostatic design basis by a service (design) factor selected for the application on the basis of two general groups of conditions. The first group considers the manufacturing and testing variables, specifically normal variations in the material, manufacture, dimensions, good handling techniques, and in the evaluation procedures in this test method and in Test Method D 1598 (Note 7). The second group considers the application or use, specifically installation, environment, temperature, hazard involved, life expectancy desired, and the degree of reliability selected (Note 8). Select the service factor so that the hydrostatic design stress obtained provides a service life for an indefinite period beyond the actual test period.

NOTE 7—Experience to date, based on data submitted to PPI, indicates that variation due to this group of conditions are usually within ±10 %, for any specific compound.

NOTE 8—It is not the intent of this standard to give service (design) factors. The service (design) factor should be selected by the design engineer after evaluating fully the service conditions and the engineering properties of the specific plastics under consideration. Alternatively, it may be specified by the authority having jurisdiction.

It is recommended that numbers selected from ANSI Standard Z17.1-1973 for Preferred Numbers, in the R10 series (25 % increments) be used, namely, 0.80, 0.63, 0.50, 0.40, 0.32, 0.25, 0.20, 0.16, 0.12, or 0.10. If smaller steps seem necessary it is recommended that the R20 series (12 % increments) be used, namely, 0.90, 0.80, 0.71, 0.63, 0.56, 0.50, 0.45, 0.40, 0.36, 0.32, 0.28, 0.25, 0.22, 0.20, 0.18, 0.16, 0.14, 0.12, 0.112, or 0.10.

5.6 *Supplemental Validation of Long-Term Hydrostatic*

Strength for Polyethylene Materials—Apply one of the two following procedures to PE material to validate the 23°C (73°F) LTHS calculated by step 5.2. Use Procedure I when it is practical to develop sufficient slit failure mode elevated temperature data for analysis by rate process equations. Procedure II may be elected if the composition will not fail in the slit mode within 6000 h at temperatures of 80°C (176°F) or higher. Conduct all validation tests with water inside the pipe specimens.

5.6.1 *Procedure I*:

5.6.1.1 Select an elevated temperature appropriate for the polyethylene material. The maximum temperature chosen should not be greater than 95°C (203°F).

5.6.1.2 Select a stress at this temperature at which all failures occur in the slit mode (a crack through the pipe wall with no visible evidence of material deformation). This set of temperature and stress is called Condition I. Test at least six pipe specimens at this Condition I until failure.

5.6.1.3 At the same temperature, select another stress about 75 to 150 psi lower than for Condition I. Test at least six specimens at this Condition II until failure.

5.6.1.4 Select a temperature 10°C (18°F) to 20°C (36°F) lower than the one in Condition I and use the same stress as Condition I. This is Condition III. Initiate testing for six specimens at this Condition III. Ideally, the selected temperature for Condition III should result in specimens that are on test for at least 1000 to 5000 h.

5.6.1.5 To validate the long-term hydrostatic strength (LTHS) on a given pipe lot, use the twelve data points from Conditions I and II and the value of the LTHS at 100 000 h for 23°C (73°F), as determined in 5.2. Using all these points, calculate the A, B, and C coefficients for the following three-coefficient rate process extrapolation equation:

$$\log t = A + \frac{B}{T} + \frac{C \log S}{T} \tag{4}$$

where:

t	=	time, h,
T	=	absolute temperature, °K (K = C + 273),
S	=	hoop stress, psi, and
A, B, C	=	constants.

5.6.1.6 Using this model, calculate the mean estimated failure time for Condition III. When the average time (log basis) for the six specimens tested at Condition III has reached this time, the extrapolation to 100 000 h to obtain the LTHS at 23°C 73°F) has been validated. (Examples are shown in Appendix X9.)

5.6.2 *Procedure II*— The LTHS is validated when either of the following is met:

5.6.2.1 Stress-rupture tests run in accordance with the procedures of this test method at 80°C or higher temperature yield all failures in the ductile mode, when run in accordance with the following program: 12 points total; 4 points in the range of 10 to 1000 h; 2 points in the range of 1000 to 4000 h; and one point over 6000 h tests at a stress at least 85 % of the long-term hydrostatic strength of the polyethylene material, or,

5.6.2.2 Six specimens which are tested at a stress of not more than 100 psi below a reference stress where all failures are ductile, have gone at least 6000 h without failure at 80°C or above. The reference stress shall be established by three specimens all failing in the ductile mode at the same temperature.

5.7 *Determination and Validation of the Hydrostatic Design Basis (HDB) for Elevated Temperatures for Polyethylene Piping Materials*

5.7.1 *Standard Method*— Determination and Validation of Elevated Temperature HDB—Develop data in accordance with 5.2 for the temperature at which an HDB is desired.

5.7.1.1 If a brittle/slit failure occurs before 10 000 h, this Standard Method is not applicable and the Alternate Method in 5.7.2 shall be used. Analyze the data to determine the linear regression equation. Extrapolate this equation to 100 000 h to determine the LTHS. If the 97.5 % LCL at 100 000 h is less than 90 % of this LTHS, consider the data unsuitable for use by this method. If all conditions are satisified, use Table 1 to determine the HDB category at this temperature.

5.7.1.2 When the HDB category has been determined, use Tables 2-5 to define the time and stress requirements needed to validate this HDB. Test ate least six specimens at the stress level determined by these tables. These specimens must have a minimum log average time exceeding the value shown in the table to validate the elevated temperature HDB. For example, to validate an HDB of 1000 psi at 140°F, this required time is 3800 h at 193°F (90°C)/600 psi or 11 300 h at 176°F (80°C)/675 psi.

NOTE 9—When an elevated temperature HDB is validated by this standard method, all lower temperature HDBs are considered validated for that material.

5.7.2 *Alternative Method*—Determination of Elevated Temperature HDB When Brittle/slit failures Occur Before 10,000 hours—If the Standard Method outlined in 5.7.1 is not appropriate for the material and test data, then use this Alternate Method to determine the HDB.

5.7.2.1 Develop data in accordance with 5.2 for the temperature at which an HDB is desired. Using only the ductile failures, determine the linear regression equation. The failure point data must be spread over at least two log decades and meet the LCL requirements of 5.7.1.1. The stress intercept at 100 00 h using this equation is the "ductile" LTHS.

5.7.2.2 To determine the brittle/slit failure performance, solve for the three coefficients of the rate process equation using Steps 1 to 4 of Procedure I in 5.6.1, or another recognized rate process method protocol. All failures must be in the brittle/slit mode. Data developed under 5.6.1 to validate a 73°F HDB can be used to solve for the three-coefficient equation as long as all specimens at the three conditions were tested to failure and resulted in brittle/slit type failures. Use the

TABLE 2 Validation of 100°F (38°C) HDB

HDB to be Validated (psi)	193°F (90°C) Test Temperature		176°F (80°C) Test Temperature	
	Stress (psi)	Time (h)	Stress (psi)	Time (h)
1600	745	300	835	1000
1250	580	300	655	1000
1000	465	300	520	1000
800	370	300	420	1000
630	295	300	330	1000
500	230	300	260	1000

TABLE 3 Validation of 120°F (49°C) HDB

HDB to be Validated (psi)	193°F(90°C) Test Temperature / 176°F(80°C) Test Temperature			
	Stress (psi)	Time (h)	Stress (psi)	Time (h)
1600	845	1100	950	3400
1250	660	1100	740	3400
1000	530	1100	595	3400
800	425	1100	475	3400
630	335	1100	375	3400
500	264	1100	300	3400

TABLE 4 Validation of 140°F (60°C) HDB

HDB to be Validated (psi)	193°F(90°C) Test Temperature / 176°F(80°C) Test Temperature			
	Stress (psi)	Time (h)	Stress (psi)	Time (h)
1250	750	3800	845	11300
1000	600	3800	675	11300
800	480	3800	540	11300
630	380	3800	425	11300
500	300	3800	340	11300
400	240	3800	270	11300

TABLE 5 Validation of 160°F (71°C) HDB

HDB to be Validated (psi)	193°F(90°C) Test Temperature / 176°F(80°C) Test Temperature			
	Stress (psi)	Time (h)	Stress (psi)	Time (h)
1250	850	12600	960	37500
1000	680	12600	770	37500
800	545	12600	615	37500
630	430	12600	480	37500
500	340	12600	385	37500
400	275	12600	305	37500

failure points at the three conditions to solve for the three unknown coefficients. Using this brittle/slit failure model, calculate the stress intercept value at 100 000 h for the temperature at which an HDB is desired. This resulting stress intercept is the "brittle/slit" LTHS.

5.7.2.3 The LTHS used to determine the HDB category as per Table 1 shall be the lower value of the ductile failure LTHS from 5.7.2.1 or this brittle/slit failure LTHS.

NOTE 10—The ISO TR/9080[4] four coefficient model may be used if it has a better statistical fit to the data.

5.8 *Pressure Rating*—Calculate the pressure rating for each diameter and wall thickness of pipe from the hydrostatic design stress (hydrostatic design basis × service factor) for the specific material in the pipe by means of the equations in 3.1.3.

6. Report

6.1 The report shall include the following:

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

6.1.2 Pipe dimensions including nominal size, average and minimum wall thickness, and average outside diameter,

6.1.3 Test temperature,

6.1.4 Test environment inside and outside of the pipe,

6.1.5 A table of the stresses in pounds-force per square inch and the time-to-failure in hours for all the specimens tested (specimens that are designated as failures after they have been under stress for more than 10 000 h shall be indicated),

6.1.6 The estimated long-term hydrostatic strength (Note 11),

6.1.7 The estimated stress at 50 years,

6.1.8 A table of the percent circumferential expansion versus time data and the estimated stress at 5.00 % expansion. This item need not be reported if previous test results show that the stress calculated for 5 % expansion is significantly greater than that reported in 6.1.6 or 6.1.7.

6.1.9 The hydrostatic design basis

6.1.10 The nature of the failures in accordance with 3.4,

6.1.11 Any unusual behavior observed in the tests,

6.1.12 If the material is polyethylene, the results of the validation in accordance with 5.6,

6.1.13 Dates of test, and

6.1.14 Name of laboratory and supervisor of the tests.

NOTE 11—The outside environment of the pipe test specimen shall be placed after the values reported.

7. Precision and Bias

7.1 No statement is made about either the precision or the bias of Test Method D 2837 for measuring the hydrostatic design basis since the result merely states whether there is conformance to the criteria for success specified in the procedure.

[4] For additional information contact the Plastic Pipe Institute Hydrostatic Stress Board Chairman, 1801 K St., NW, Suite 600 K, Washington, DC 20006.

APPENDIXES

(Nonmandatory Information)

X1. LEAST SQUARES CALCULATIONS FOR LONG-TERM HYDROSTATIC STRENGTH

X1.1 The following symbols are used (Note X1.1):

N = number of points on the cycles to failure versus stress plot
f = logarithm of failure stress, psi,
F = arithmetic average of all f values,
h = logarithm of failure time, h
H = arithmetic average of all h values.

The equation of the straight line is:

$$h = a + bf \tag{X1.1}$$

X1.1.1 Compute the three quantities:

$$U = \Sigma f^2 - [(\Sigma f)^2/N] \text{ (or } \Sigma f^2 - NF^2) \tag{X1.2}$$

$$V = \Sigma h^2 - [(\Sigma h)^2/N] \text{ (or } \Sigma h^2 - NH^2) \tag{X1.3}$$

$$W = \Sigma f h - [(\Sigma f)(\Sigma h)/N] \text{ (or } \Sigma f h - NFH) \tag{X1.4}$$

X1.1.2 Calculate a and b as follows:

$$b = W/U \tag{X1.5}$$

and

$$a = H - bF \tag{X1.6}$$

If b is positive, the data are unsuitable for evaluating the material.

X1.1.3 Substitute these values of a and b into the equation:

$$h = a + bf \tag{X1.7}$$

X1.1.4 Arbitrarily select three convenient values for f and calculate h for each. The values of f should not be chosen too close to one another. Plot these three pairs of values for f and h. If these three points do not lie on a straight line, there is a mistake in the calculations.

X1.1.5 A sample calculation made in accordance with Appendix X1 is given in Appendix X6.

NOTE X1.1—All logarithms are to the base 10. Use 5-place tables for calculations. A sample calculation is given in Appendix X6.

X2. CALCULATIONS OF LOWER CONFIDENCE LIMIT

X2.1 Let $f_{100\,000}$ represent the value of stress corresponding to 100 000 h failure-time. Then:

$$f_{100\,000} = (5 - a)/b \tag{X2.1}$$

X2.2 The lower confidence value of stress at 100 000 h is given by the following calculations:

X2.2.1 Calculate $D = 5 - H$.

X2.2.2 Calculate the variance,

$$s^2 = [1/(N - 2)][V - (W^2/U)] \tag{X2.2}$$

and its square root, s, the standard deviation.

X2.2.3 Substitute the value, t, of Student's t distribution, from Appendix X4 corresponding to $N - 2$ degrees of freedom at the two-sided 5 % level of significance (Note X2.1). See also Table X2.1.

X2.2.4 Calculate the quantity:

$$M = b^2 - (t^2 s^2/U) \tag{X2.3}$$

If M is negative or zero, the slope of log cycles versus stress is not significantly different from zero. In this case, the lower confidence limit cannot be calculated, and the data are unreliable for the evaluation of the material. The calculations below should be carried out only when the value of M is positive.

X2.2.5 Calculate the quantity:

$$L = [bD - ts\sqrt{(D^2/U) + (M/N)}]/M \tag{X2.4}$$

(See Appendix X5.)

X2.2.6 The lower confidence limit of $f_{100\,000}$ is equal to $L + F$ (Note X2.2).

NOTE X2.1—For instance, Statistical Methods for Chemists by W. J. Youden, Page 119, Wiley, (1951) New York.

NOTE X2.2—97.5 % of the expected failures at 100 000 h will be above this stress.

TABLE X2.1 Calculations

Degrees of Freedom, $N - 2$	Students "t"[A]	Degrees of Freedom, $N - 2$	Students "t"[A]	Degrees of Freedom, $N - 2$	Students "t"[A]
1	12.7062	46	2.0129	91	1.9864
2	4.3027	47	2.0117	92	1.9861
3	3.1824	48	2.0106	93	1.9858
4	2.7764	49	2.0096	94	1.9855
5	2.5706	50	2.0086	95	1.9853
6	2.4469	51	2.0076	96	1.9850
7	2.3646	52	2.0066	97	1.9847
8	2.3060	53	2.0057	98	1.9845
9	2.2622	54	2.0049	99	1.9842
10	2.2281	55	2.0040	100	1.9840
11	2.2010	56	2.0032	102	1.9835
12	2.1788	57	2.0025	104	1.9830
13	2.1604	58	2.0017	106	1.9826
14	2.1448	59	2.0010	108	1.9822
15	2.1315	60	2.0003	110	1.9818
16	2.1199	61	1.9996	112	1.9814
17	2.1098	62	1.9990	114	1.9810
18	2.1009	63	1.9983	116	1.9806
19	2.0930	64	1.9977	118	1.9803
20	2.0860	65	1.9971	120	1.9799
21	2.0796	66	1.9966	122	1.9796
22	2.0739	67	1.9960	124	1.9703
23	2.0687	68	1.9955	126	1.9790
24	2.0639	69	1.9949	128	1.9787
25	2.0595	70	1.9944	130	1.9784
26	2.0555	71	1.9939	132	1.9781