Standard Test Methods for
Compressive and Flexural Creep and Creep-Rupture of Plastic Lumber and Shapes[1]

This standard is issued under the fixed designation D 6112; 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 These test methods cover the determination of the creep and creep-rupture properties of plastic lumber and shapes, when loaded in compression or flexure under specified environmental conditions. Test specimens in the "as-manufactured" form are employed. As such, these are test methods for evaluating the properties of plastic lumber or shapes as a product and not material property test methods.

1.2 Plastic lumber and plastic shapes are currently made predominantly with recycled plastics. However, this test method would also be applicable to similar manufactured plastic products made from virgin resins where the product is non-homogenous in the cross-section.

1.3 The values stated in inch–pound units are to be regarded as the standard. The values given in parentheses are for information only.

1.4 *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.*

NOTE 1—There is no similar or equivalent ISO standard.

2. Referenced Documents

2.1 *ASTM Standards:*

D 543 Test Method for Resistance of Plastics to Chemical Reagents[2]

D 883 Terminology Relating to Plastics[2]

D 2990 Standard Test Methods for Tensile, Compressive, and Flexural Creep and Creep Rupture of Plastics[3]

D 4000 Classification System for Specifying Plastics[3]

D 5033 Guide for the Development of Standards Relating to the Proper Use of Recycled Plastics[4]

D 5947 Test Methods for Physical Dimensions of Solid Plastics Specimens[4]

E 4 Practices for Load Verification of Testing Machines[5]

3. Terminology

3.1 *Definitions:*

3.1.1 *compression—in a compressive creep test,* the decrease in length produced in the gage length or the total length of a test specimen.

3.1.2 *creep modulus*—the ratio of initial applied stress to creep strain.

3.1.3 *creep strain*—the total strain, at any given time, produced by the applied stress during a creep test.

3.1.3.1 *Discussion*—The term creep, as used in this test method, reflects current plastics engineering usage. In scientific practice, creep is often defined to be the nonelastic portion of strain. However, this definition is not applicable to existing engineering formulas. Plastics have a wide spectrum of retardation times, and elastic portions of strain cannot be separated in practice from nonelastic. Therefore, wherever "strain" is mentioned in these test methods, it refers to the sum of elastic strain plus the additional strain with time.

3.1.4 *deflection—in a flexural creep test,* the change in mid-span position of a test specimen.

3.1.5 *deformation*—a change in shape, size or position of a test specimen as a result of compression, deflection, or extension:

3.1.6 *plastic lumber, n*— a manufactured product composed of more than 50 weight percent resin, and in which the product generally is rectangular in cross-section and typically supplied in board and dimensional lumber sizes, may be filled or unfilled, and may be composed of single or multiple resin blends.

3.1.7 *plastic shape, n*— a manufactured product composed of more than 50 weight percent resin, and in which the product generally is not rectangular in cross-section, may be filled or unfilled, and may be composed of single or multiple resin blends.

3.1.8 *resin, n*—a solid or pseudo-solid organic material often of high molecular weight, that exhibits a tendency to flow when subjected to stress, usually has a softening or melting range, and usually fractures conchoidally. (See Terminology D 883.)

3.1.8.1 *Discussion*—In a broad sense, the term is used to designate any polymer that is a basic material for plastics.

3.1.9 *stress—for compressive creep,* the ratio of the applied load to the initial cross-sectional area. For flexural creep, maximum fiber stress is calculated according to Eq 1.

3.1.10 Additional definition of terms applying to this test method appear in Terminology D 883 and Guide D 5033.

4. Summary of Test Method

4.1 These test methods consist of measuring the deflection or compression as a function of time and time-to-rupture, or failure of a specimen subject to constant flexural or compressive load under specified environmental conditions.

4.2 The four-point loading a outlined in this testing standard shall be used for the flexural creep tests.

4.3 Compressive loading as outlined in this testing standard shall be used for the compressive creep tests.

4.4 These test methods represent modifications of the compressive and flexural creep and creep rupture test methods specified in Test Methods D 2990.

5. Significance and Use

5.1 Data from creep and creep-rupture tests are necessary to predict the creep modulus and strength of materials under long-term loads and to predict dimensional changes that may occur as a result of such loads.

5.2 Data from these test methods can be used to characterize plastic lumber: for comparison purposes, for the design of fabricated parts, to determine long-term performance under constant load, and under certain conditions, for specification purposes.

5.3 For many products, there may be a specification that requires the use of this test method, but with some procedural modifications that take precedence when adhering to the specification. Therefore, it is advisable to refer to that product specification before using this test method. Table 1 in Classification D 4000 lists the ASTM materials standards that currently exist.

6. Apparatus

6.1 *General*:

6.1.1 *Loading System*:

6.1.1.1 The loading system must be so designed that the load applied and maintained on the specimen is within ±1 % of the desired load. The loading mechanism must allow reproductively rapid and smooth loading as specified in 11.1.3. In creep-rupture tests, provision must be made to ensure that shock loading, caused by a specimen failure, is not transferred to other specimens undergoing testing. The accuracy of the loading system shall be verified at least once each year in accordance with Practices E 4.

6.1.1.2 Loading systems that provide a mechanical advantage require careful design to maintain constant load throughout the test. For example, lever systems must be designed so that the load does not change as the lever arm moves during the test.

6.1.2 *Compression and Deflection Measurements*:

6.1.2.1 The accuracy of the deformation measuring device shall be within ±1 % of the deformation to be measured.

6.1.2.2 Deformation measuring devices shall be calibrated against a precision micrometer screw or other suitable standard under conditions are nearly identical as possible with those encountered in the test. Caution is necessary when using deformation measuring devices whose calibration is subject to drifting with time and is dependent on temperature and humidity.

6.1.2.3 Deformation measuring devices shall be firmly attached to or seated on the specimen so that no slippage occurs. Electrical resistance gages are suitable only if the material tested will permit perfect adhesion to the specimen and if they are consistent with 6.2.1

6.1.3 *Time Measurement*— The accuracy of the time measuring device shall be ±1 % of the time-to-rupture or failure or the elapsed time of each creep measurement, or both.

6.1.4 *Temperature Control and Measurement*:

6.1.4.1 The temperature of the test space, especially close to the gage length of the specimen, shall be maintained within ±2°C by a suitable automatic device and shall be stated in reporting the results.

NOTE 2—The thermal contraction and expansion associated with small temperature changes during the test may produce changes in the apparent creep rate, especially near transition temperatures.

6.1.4.2 Care must be taken to ensure accurate temperature measurements over the gage length of the specimen throughout the test. The temperature measuring devices shall be checked regularly against temperature standards and shall indicate the temperature of the specimen gage area.

6.1.4.3 Temperature measurements shall be made at frequent intervals, or continuously recorded to ensure an accurate determination of the average test temperature and compliance with 6.1.5.

6.1.5 *Environmental Control and Measurements*:

6.1.5.1 When the test environment is air, the relative humidity shall be controlled to 50 ± 5 % during the test unless otherwise specified, or unless the creep behavior of the material under testing has been shown to be unaffected by humidity. The controlling and measuring instruments shall be stable for long time intervals and accurate to within ±1 %. (The control of relative humidity is known to be difficult at temperatures much outside the range from 50 to 104°F (10 to 40°C).)

6.1.5.2 If, for any reason, the specified relative humidity cannot be achieved or the test is conducted to determine the sensitivity of the product to high humidity, the actual average value and fluctuation of relative humidity used should be reported.

6.1.5.3 The composition of the test environment shall be maintained constant throughout the test.

NOTE 3—**Warning:** Safety precautions should be taken to void personal contact, to eliminate toxic vapors, and to guard against explosion hazards in accordance with any possible hazardous nature of the particular environment being used.

6.1.6 *Vibration Control*—Creep tests are quite sensitive to shock and vibration. The location of the apparatus, the test equipment, and mounting shall be so designated that the specimen is isolated from vibration. Multiple-station test equipment must be of sufficient rigidity so that no significant

deflection occurs in the test equipment during creep or creep-rupture testing. During time-to-rupture or failure, means to prevent jarring of other test specimens by the falling load from a failed test specimen shall be provided by a suitable net or cushion.

6.2 *Compressive Creep*:

6.2.1 *Platens*—Parallel platens shall be used to apply the load to the unconfined-type specimen (see 8.2). One of the platens of the machine shall preferably be self-aligning and shall, in order that the load may be applied evenly over the face of the specimen, be arranged so that the specimen is accurately centered and the resultant of the load is through its center.

6.2.2 The compression of specimen gage length under load shall be measured by means of any device that will not influence the specimen behavior by mechanical (undesirable deformation, notches, etc.) physical (heating of specimen, etc.), or chemical effects. Alternatively, the compression of the specimen can be measured using platen displacement with the entire length of the specimen serving as the gage length.

6.3 *Flexural Creep*:

6.3.1 *Test Rack*—A rigid test rack shall be used to provide support of the test specimen at both ends with a span equal to 16 (tolerant +4 and −2) times the depth of the specimen. In order to avoid excessive indentation of the specimen, the radius of the support shall be a minimum of 0.5 in. (12.7 mm) and up to 1.5 times the depth of the specimen. Sufficient space must be allowed below the specimen for dead-weight loading.

6.3.2 *Loading Beam*— The loading beam shall be configured with loading noses with cylindrical surfaces (see Fig. 1). The radius of noses shall be at least 0.5 in. (12.7 mm) or all specimens. For large specimens the radius of the supports may be up to 1.5 times the specimen depth.

6.3.3 A four point loading arrangement shall be used as shown in Fig. 1.

6.3.4 For flexural testing the deflection of the specimen shall be measured at the midpoint of the load span at the bottom face of the specimen.

7. Reagents

7.1 *Purity of Reagents*—Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society,

where such specification are available[6]. Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

7.2 *Purity of Water*— Unless otherwise indicated, references to water shall be understood to mean distilled water or water of equal purity.

7.3 *Specified Reagents*—Should this test method be referenced in a material specification, the specific reagent to be used shall be as stipulated in the specification.

7.4 *Standard Reagents*—A list of standard reagents is also available in Test Method D 543.

8. Test Specimen

8.1 *General*:

8.1.1 Test specimens may be made by any of the techniques normally employed to produce plastic lumber. When the testing objective is to obtain design data, the method of sample fabrication shall be the same as that used in the application.

8.1.2 In the case of materials whose dimensions are known to change significantly due to the specified environment alone (for example, the shrinkage of some thermosetting plastics due to post-curing at elevated temperatures), provision shall be made to test unloaded control specimens alongside the test specimen so that compensation may be made for changes other than creep. A minimum of three control specimens shall be tested at each test temperature.

8.1.3 In creep testing at a single temperature, the minimum number of test specimens at each stress shall be two if four or more levels of stress are used or three if fewer than four levels are used.

8.1.4 In creep-rupture testing, a minimum of two specimens shall be tested at each of the stress levels specified in 10.2.1 at each temperature.

NOTE 4—The scatter of creep-rupture data is considerable, with one half to a full decade of variation in time-to-rupture being typical. Therefore, it may be necessary to test more than two specimens at each stress level to obtain satisfactory results.

8.2 *Compressive Creep*:

8.2.1 The standard test specimen shall be in the form of a right prism. With the exception that specimen cross sections are the full sections of any manufactured plastic lumber or shape. Surfaces of the test specimens shall be plane and parallel.

8.2.2 Test specimens for determining compressive properties of plastic lumber and shapes shall be cut from the "as manufactured" profile. Great care shall be taken in cutting and machining the ends so that smooth, flat parallel surfaces and sharp, clean edges to within $\frac{1}{300}$ (0.0033) of the specimen length perpendicular to the long axis of the specimen results.
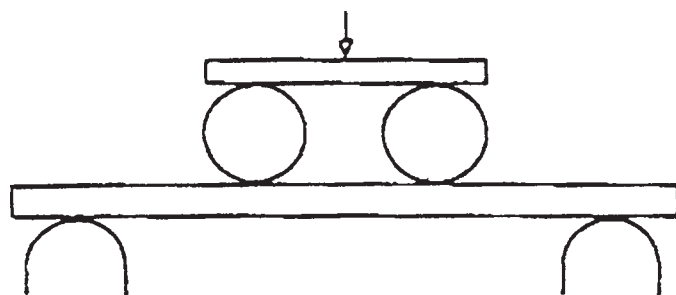
NOTE—Minimum radius = 0.5 in. (12.7 mm); maximum radius = 1.5 times the specimen depth.

FIG. 1 Four Point Loading and Support Noses at Maximum Radius

[6] *Reagent Chemicals, American Chemical Society Specifications*, American Chemical Society, Washington, DC. For suggestions on the testing of reagents not listed by the American Chemical Society, see *Analar Standards for Laboratory Chemicals*, BDH Ltd., Poole, Derner, U.K., and the *United States Pharmacopeia and National Formulary*, U.S. Pharmacopeial Convention, Inc. (USPC), Rockville, MD.

Plastic lumber is generally nonuniform through the cross-section; no machining operations other than those required to provide flat, parallel ends shall be carried out.

8.2.2.1 The standard test specimen, except as indicated in 8.2.2.2 to 8.2.2.3, shall be in the form of a right cylinder or prism whose height is twice its *minimum* width or diameter.

8.2.2.2 For rod material, the test specimen shall have a diameter equal to the diameter of the rod and whose height is twice its diameter.

8.2.2.3 When testing hollow profiles, the test specimen shall have a minimum length equal to twice its minimum cross sectional dimension.

8.3 *Flexural Creep*:

8.3.1 The specimens shall be full size as manufactured. The original surfaces shall be unaltered.

8.3.2 For flatwise (plank) tests, the depth of the specimen shall be the thickness, or smaller dimension, of the material. For edgewise (joist) tests the width becomes the smaller dimension and depth the larger. For all tests, the support span shall be 16 (tolerance +4 and −2) times the depth of the beam. The specimen shall be long enough to allow for overhanging on each end of at least 10 % of the support span, but in no case less than 0.25 in. (6.4 mm) on each end. Overhand shall be sufficient to prevent the specimen from slipping through the supports.

9. Conditioning

9.1 The specimen shall be preconditioned in the test environment for at least 48 h prior to being tested or for a longer period if needed to establish an equilibrium condition. Those materials whose creep properties are suspected to be affected by moisture content shall be brought to moisture equilibrium appropriate to the test conditions prior to testing.

9.2 If warranted, based on projected usage, the test specimen should be submerged in water for at least 24 h or until it achieves an equilibrium moisture content prior to conditioning. The ends of the test specimen should be taped prior to water immersion.

10. Selection of Test Conditions

10.1 *Test Temperatures*—Selection of temperatures for creep and creep-rupture testing depends on the intended use of the test results and shall be made as follows:

10.1.1 To characterize a material, select two or more test temperatures to cover the useful temperature range usually at elevated temperatures, in suitable increments that reflect the variation of the creep of the material with temperature and transitions of the material. Unless actual conditions warrant otherwise, test temperatures of 50, 73.4, and 104°F (10, 23, and 40°C) are recommended.

10.1.2 To obtain design data, the test temperatures and environment shall be the same as those of the intended end-use application.

10.1.3 To obtain the stress for 1 % strain at 1000 h (see 10.3.2) or for other simple material comparisons such as data sheets, use the recommended test temperatures cited in 10.1.1.

10.2 *Creep-Rupture*:

10.2.1 At each test temperature, make creep-rupture tests at a minimum of seven stress levels selected so as to produce rupture at approximately the following times: 1, 10, 30, 100, 300, 1000, and 3000 h.

10.2.1.1 The objective of these tests is to produce at each test temperature, a curve of stress-at-rupture versus time-to-rupture, often called a "creep-rupture envelope," which indicated a limit of a material's load-bearing capability at the test temperature. For the prediction of long-term performance, for example, in the design of parts that will bear constant loads six months or longer, test times longer than 3000 h are usually necessary, particularly at elevated temperatures where heat aging of the material may be occurring, and in aggressive environments, both of which can greatly affect creep-rupture.

10.2.2 For materials that fail catastrophically (that is, with negligible yielding, drawing, or flowing) measure and report the time-to-rupture. For materials that yield, draw, or flow significantly prior to rupture, measure and report the time at the onset of tertiary creep (onset of yielding, flowing, or drawing) shall be considered the time-to-failure and shall be measured and reported. For materials that yield, draw, or flow, creep strain may have to be measured with a recorder.

10.3 *Creep*:

10.3.1 To obtain design data or to characterize a material, select stress levels as follows:

10.3.1.1 For materials that show linear viscoelasticity, that is, successive creep modulus versus time for different stresses that superimpose upon each other (Boltzman superposition principle,[7] select a minimum of three stress levels for each temperature of interest.

10.3.1.2 For materials that are significantly affected by stress, select at least five stresses (and preferably more) for each temperature of interest.

10.3.1.3 Select stress levels in approximately even increments up to the 1000–h creep-rupture stress: stress levels above 1000 psi (6.9 MPa) to the nearest 500 psi (3.4 MPa); stress levels below 1000 psi (6.9 MPa) to the nearest 100 psi (0.7 MPa).

10.3.1.4 Do not use stress levels that produce failure in less than 1000 h in creep testing.

10.3.2 For simple material comparisons, as for data sheets and the like, determine the stress to produce 1 % strain in 1000 h. Do this by selecting several loads to produce strains in the approximate range of 1 % (both somewhat greater and less than 1 % in 1000 h) and plotting a 1000–h isochronous stress-strain curve from which the stress to produce 1 % strain may be determined by interpolation.

NOTE 5—Isochronous stress-strain curves are cartesian plots of the applied stress used in the creep test versus the creep strain at a specific time, in this case 1000 h. Since only one point of an isochronous plot is obtained from each creep test, it is usually necessary to run creep tests at least three stress levels (and preferably more) to obtain an isochronous plot (See Fig. 2).

11. Procedure

11.1 *General*:

11.1.1 Mount a properly conditioned and measured specimen in the compressive creep fixture of flexural creep rack. If

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[7] Nielsen, L.E., *Mechanical Properties of Polymers*, Reinhold Publishing Corp., New York, NY, 1962.
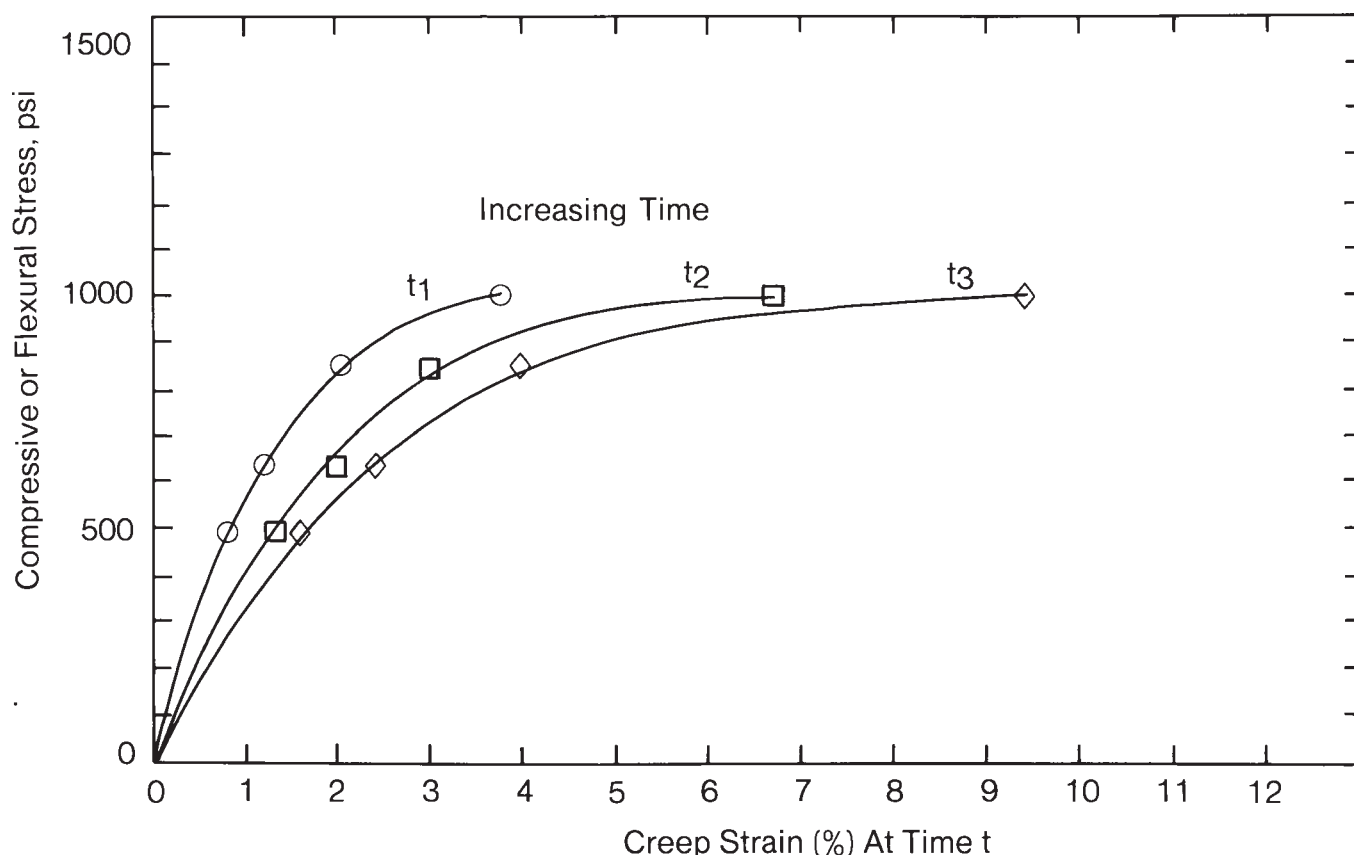
FIG. 2 Cartesian Isochronous Stress Strain Curves at Various Times

necessary, mount a properly conditioned and measured control specimen alongside the test specimen in the same manner.

11.1.2 Attach the deformation measuring devices to the specimen (and control specimen) or, if these are optical devices, install ready for measurements. Make the initial or reference measurement for compression or deflection.

11.1.2.1 If the test environment would be disturbed during the attachment of the deformation measuring device, mount the device prior to mounting the specimen.

11.1.3 Apply the full load rapidly and smoothly to the specimen, preferably in 1 to 5 s. In no case shall the loading time exceed 5 s. Start the timing at the onset of loading.

11.1.4 If an environmental agent is used, apply it to the entire gage length of the specimen immediately after loading.

11.1.4.1 If the environmental agent is volatile, cover the specimen to retard evaporation without affecting the applied load. Replenish volatile agents periodically.

NOTE 6—For liquid environmental agents a cotton swab, film, or other device may be wrapped or sealed around the gage length or span of the specimen, and the liquid agent applied to saturate the swab.

11.1.5 Measure the compression or flexure of the specimen in accordance with the following approximate time schedule: 1, 6, 12, and 30 min; 1, 2, 5, 20, 50, 100, 200, 500, 700, and 1000 h. For creep tests longer than 1000 h, measure deformation at least monthly.

11.1.5.1 If discontinuities in the creep strain versus time plot are suspected or encountered, reading should be taken more frequently than scheduled above.

11.1.6 Measure temperature, relative humidity, and other environmental variables and deformation of control specimen in accordance with the same schedule as that for deformation of the test specimen.

11.1.7 Upon completion of the test interval without rupture, remove the load rapidly and smoothly.

NOTE 7—If desired, measurements of the recovery can be initiated on the same schedule as used in 11.1.5 during the load application. Calculate recovery strain as described in 12.2.2.

11.2 *Flexural Creep*:

11.2.1 Flexural deflection shall be measured at the bottom of the test specimen at the midpoint of the load span.

11.2.2 Measure the width and thickness or diameter of the specimen to a precision of 1 % of the measured dimension at several points along its length. Calculate and record the minimum value of the cross-sectional area (see Test Methods D 5947 for additional information).

11.3 *Compressive Creep*—Measure the width and thickness or diameter of the specimen to a precision of 1 % of the measured dimension at several points along its length. Calculate and record the minimum value of the cross-sectional area. Measure the length of the specimen at several points and record the average value (see Test Methods D 5947 for additional information).

12. Calculation

12.1 *General*:

12.1.1 When a material shows a significant dimensional change due to the environment alone, either of the following approaches may be used, depending on the intended use of the results:

12.1.2 Correct each measurement of deformation under load by the algebraic addition to it of the average deformation measured on three nonloaded control specimens at the same time and at the same temperature. Contraction of the control specimens used for compressive measurements shall be considered negative (−), expansion positive (+). Upward deflection of the control specimens used for flexural measurements shall be considered positive (+); downward shall be considered negative (−). Calculate corrected strain using the deformation corrected for or dimensional change due to the environment. Multiply corrected strain by 100 to obtain percent corrected strain.

12.1.3 If, because of the intended use of the results, it is desired not to correct the deformation under load for significant dimensional change due to the environment alone, then the strain calculated in accordance with 12.2.2 or 13.3.1 shall be called uncorrected strain. Calculate the strain change due to the environment in accordance with 12.2.2 or 13.3.1 by using the average deformation in the control specimen. Multiply by 100 to obtain percent strain change due to the environment. Contraction of the control specimens used for compressive measurements shall be considered negative (−), expansion positive (+). Upward deflection of the control specimens used

for flexural measurements shall be considered positive (+), downward negative (−).

12.1.4 Calculate creep modulus in megapascals by dividing the initial stress by the strain at the times specified in 11.1.5.

Note 8—For purposes of comparing materials, the plot of creep modulus versus time not only realistically ranks materials but also provides modulus values for use in many design equations (see Fig. 3).

12.1.5 At each test temperature, calculate a statistical least squares regression equation of log stress versus log time-to-rupture or failure. From the regression equation calculate the stress-to-rupture failure in megapascals at 1000 h (see Fig. 4).

12.1.6 To calculate the stress to produce 1 % strain at 1000 h, plot at each test temperature the 1000–h isochronous stress-strain curve (see Fig. 2) and interpolate for the stress at 1 % strain. The isochronous stress-strain curve at 1000 h is obtained from several (at least three, and preferably more) creep curves at different stresses by plotting stress versus strain calculated from deformation measurements at 1000 h.

12.1.6.1 Isochronous stress-strain curves may be plotted at times other than 1000 h for purposes of analysis or for specialized design situations involving relatively short-time loads and materials that show pronounced creep at such times. For long-term loading and in general, however, creep modulus curves are more useful.

12.2 *Compressive Creep*:

12.2.1 For compressive measurements, calculate the stresses for each specimen in megapascals (or pounds-force per
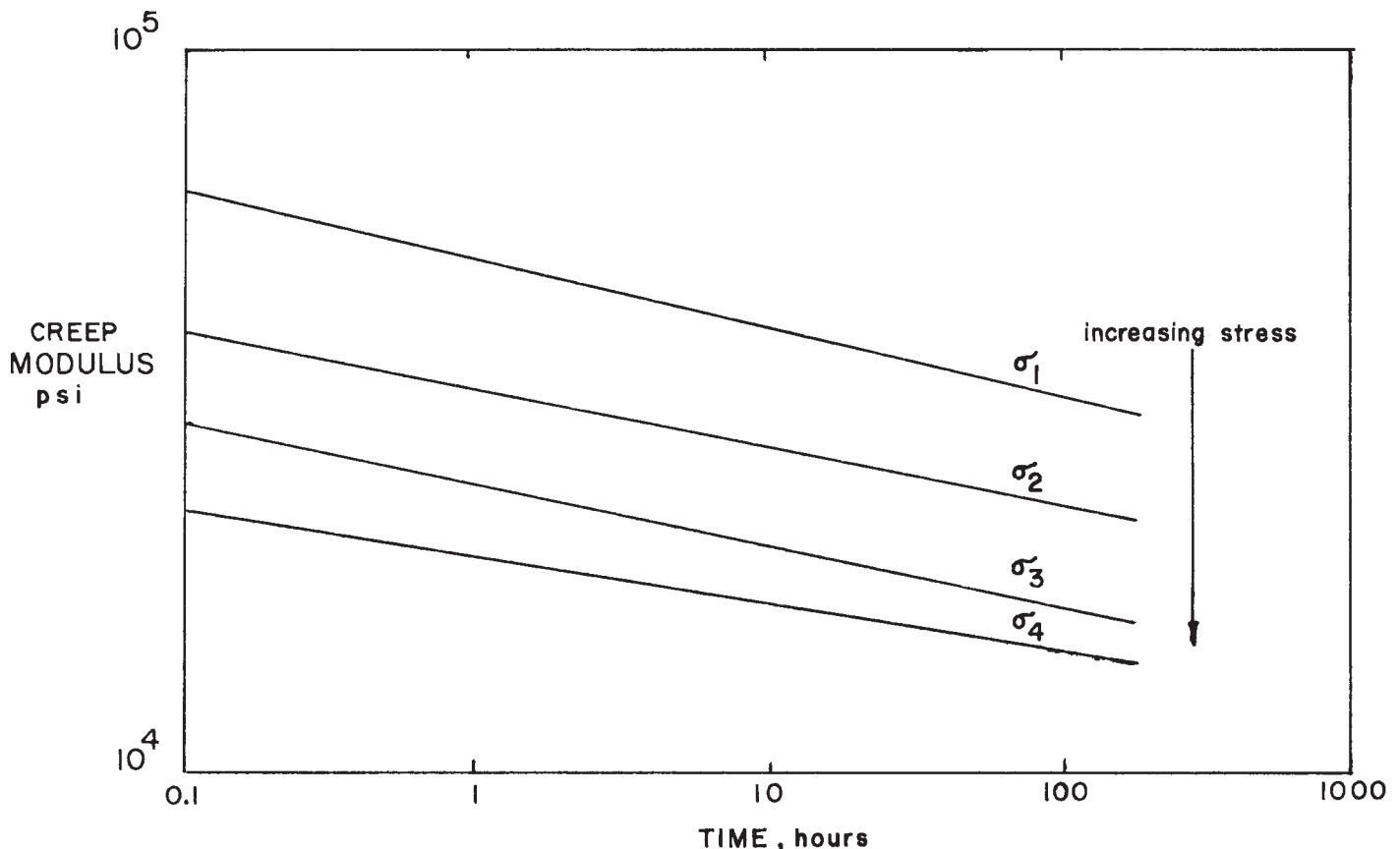

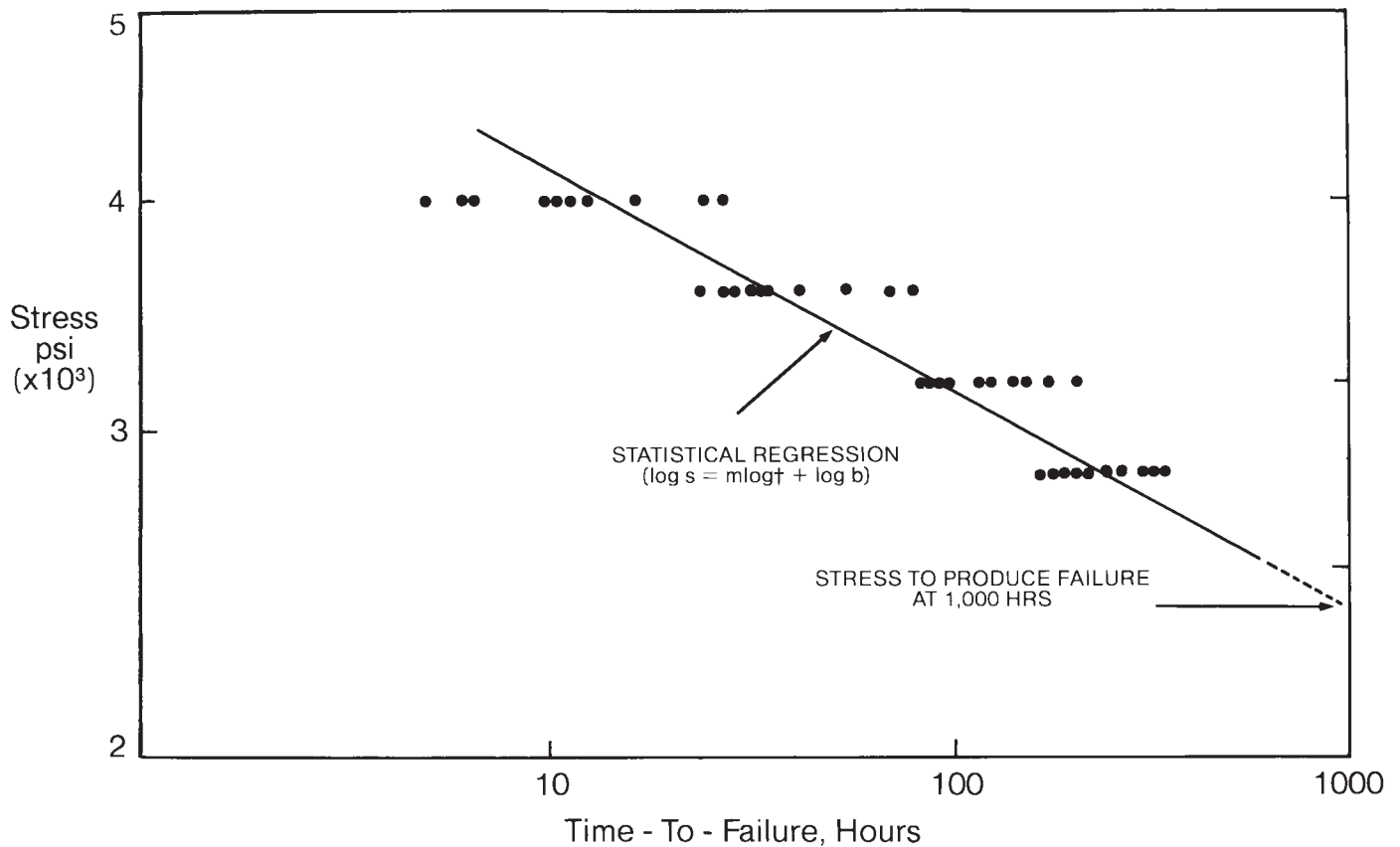FIG. 3 Logarithmic Creep Modulus Versus Time Curves at Various Stress Levels

FIG. 4 Logarithmic Time-to-Failure (Stress Rupture) Curve

square inch) by dividing the load by the average initial or effective cross-sectional area.

12.2.2 Calculate strain by dividing the extension or compression at the times specified in 11.1.5 by the initial gage length of the conditioned specimen; multiply strain by 100 to obtain percent strain.

12.3 *Flexural Creep*:

12.3.1 For flexural measurements, calculate the maximum fiber stress for each specimen in megapascals as follows:

$$S = PL/bd^2 \qquad (1)$$

where:
S = stress in outer fiber throughout load span, psi (MPa),
P = load at a given point on the load-deflection curve, lb (N)
L = support span, in. (mm),
b = width of beam, in. (mm), and
d = depth of beam, in. (mm).

Note 9—Eq 1 represents only a first-order approximation to the actual flexural stress because the distribution of stress across the section becomes increasingly nonlinear as creep occurs. Its use is consistent with Test Methods D 2990.

12.3.2 Calculate the maximum strain in the outer fiber at the mid-span as follows:

$$r = 4.70 \, Dd/L^2 \qquad (2)$$

where:
r = maximum strain, in./in. (mm/mm),

D = maximum deflection at mid-span, in. (mm),
d = depth of beam, in. (mm), and
L = support span, in. (mm).
Multiply strain by 100 to obtain percent strain.

13. Report

13.1 Report the following information:

13.1.1 Complete identification of the material tested, including type, source, manufacturer's code number, form, principal dimensions, and previous history,

13.1.2 Laboratory name,

13.1.3 Date of test,

13.1.4 Dimensions of the test specimen,

13.1.5 All pertinent information on composition, preparation, date of manufacture, type of molding, annealing, etc.,

13.1.6 Preconditioning used and description of test conditions, including the relative humidity, temperatures, as well as concentration and composition of the environment other than air, loads used, type loading, etc.,

13.2 For each test temperature, plot log strain in percent versus log time in hours under load with stress as a parameter (see Fig. 5),

13.2.1 Where deformation measurements of loaded specimens have been corrected from unloaded control specimens, plot log corrected strain (in percent) versus log time (in hours) under load, and on the same graph also plot the log average dimensional change (in percent) due to the environment alone versus log time,
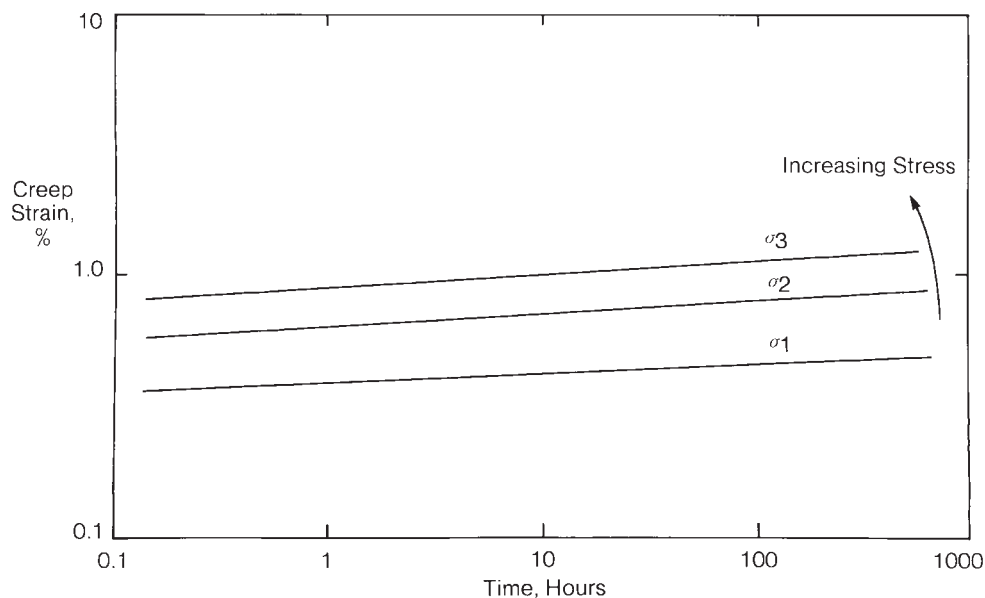
FIG. 5 Logarithmic Creep Strain Versus Time Curves at Various Stress Levels

13.2.2 Where significant changes in deformation due to the environment alone have occurred, but because of the intended use of the results it is desired not to correct the deformation under load, then plot log uncorrected strain, in percent, versus log time in hours under load, and on the same graph plot the log average strain change (in percent) of the control specimen versus log time, and

13.2.3 When a material shows a significant dimensional change due to the environment alone, any properties calculated from the creep data (such as creep modulus or isochronous stress-strain curves) shall be labeled corrected or uncorrected, depending on which approach is used.

14. Precision and Bias

14.1 These are new test methods for which precision and bias have not been determined. Interlaboratory studies will be initiated to define the reproducibility of test specimens prepared using this practice.

14.2 It is the intent of Subcommittee D20.20 to publish these test methods and then begin an investigation of its precision and bias. Anyone wishing to participate in this work may contact the Chairman of Subcommittee D20.20 at ASTM Headquarters.

15. Keywords

15.1 creep; creep-rupture; plastic lumber; recycled plastic

APPENDIXES

(Nonmandatory Information)

X1. INTRODUCTION

X1.1 Since the properties of viscoelastic materials are dependent on time-, temperature-, and rate-of-loading, an instantaneous test result cannot be expected to show how a material will behave when subjected to stress or deformation for an extended period of time. Therefore, values of modulus and strength should be obtained under conditions (stress, time, and so forth) that simulate the end-use application, and be used in engineering design.

X2. CREEP CURVE

X2.1 The creep test measures the dimensional changes that occur during time under a constant static load, while the creep rupture test measures the time to break under a constant load. Creep is the progressive deformation of a material at constant load (stress). A constant load is applied to a specimen in selected loading configurations, (such as, tension, flexure, or compression) at constant temperature and the deformation is measured as a function of time.

X2.2 Following an initial rapid elongation (ϵ_o) upon application of the load (ϵ_o may be considered to consist of the elastic (ϵ_o) and the plastic (ϵ_o)), the following occurs:

X2.2.1 The creep rate decreases rapidly with time, (primary creep, Stage I), then

X2.2.2 It reaches a steady-state value (secondary creep, Stage II), followed by

X2.2.3 A rapid increase and fracture (tertiary creep, Stage III).

Note X2.1—This is an idealized curve. Some materials do not have a secondary stage, while tertiary creep usually occurs at high stresses and for ductile materials.

Note X2.2—Since the specimen elongates and decreases in cross-sectional area, the axial stress increases. Therefore, in a constant-load creep test the onset of Stage III shows up earlier than in a constant-stress test (see dotted line in Fig. X2.1)

Note X2.3—In some terminologies the instantaneous strain (ϵ_o) is often called the first stage, in which case we have four stages of creep.

X2.3 The strain, shown as ϵ_o occurs instantaneously upon application of the load. Even though the applied stress is below the yield stress, some of this strain is not totally recoverable. Although this strain is not really creep it is very important since it constitutes a considerable fraction of the allowable total strain in designing. Therefore, it should be included in all calculations, especially of the creep modulus.

Note X2.4—In cases where this instantaneous strain is subtracted from the total strain, the creep curve must start at the origin of the time/strain coordinates.

X2.4 Due to the long times involved, creep curves are usually plotted on logarithmic scales where the data is generally linear. The three curves shown in Figs. X2.2-X2.4 are an example.
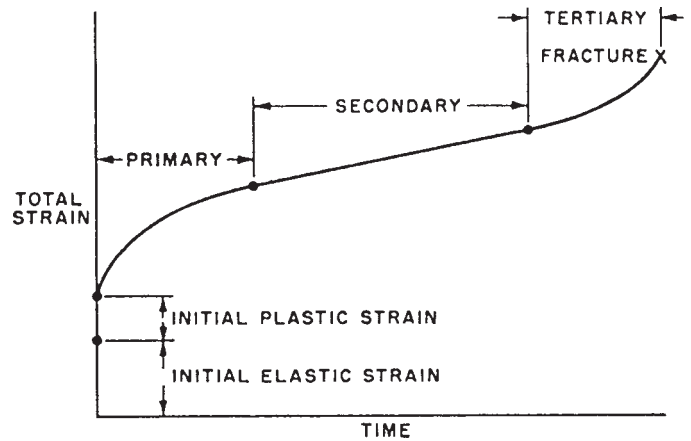
Note 1—The segregation of creep data into instantaneous, primary, and secondary stages is dependent upon the time scale of the plot.

Note 2—The parameters, ϵ_e, ϵ_p, and ϵ_o are not obtainable using these test methods (see Note 4). However, such factors may be separately defined for the sake of stress analysis. Any such definitions can be more or less arbitrary with respect to the time-dependent material behavior.
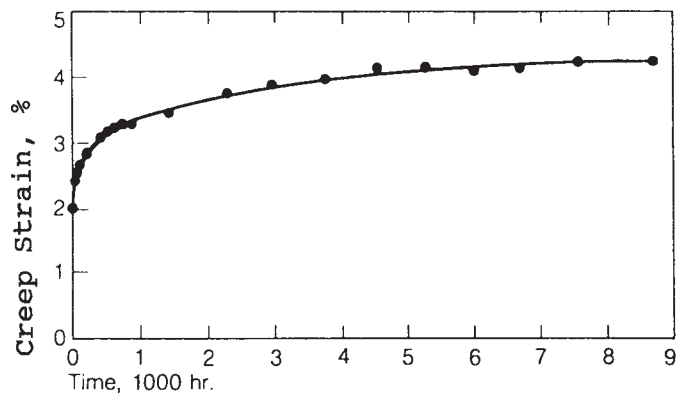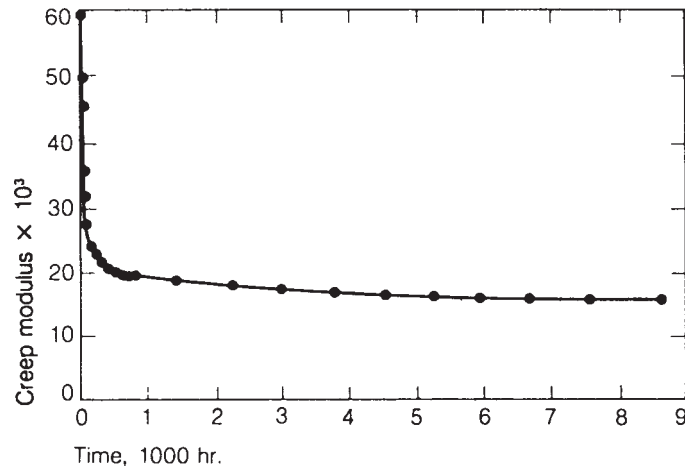
FIG. X2.1 Creep Curve

FIG. X2.2 Tensile-Creep Curve of PTFE at 650 psi, 23°C Creep Strain Versus Time

X2.5 As the stress levels increase the creep modulus will be lowered.

NOTE—Modulus = Applied Stress/Total Creep Strain.
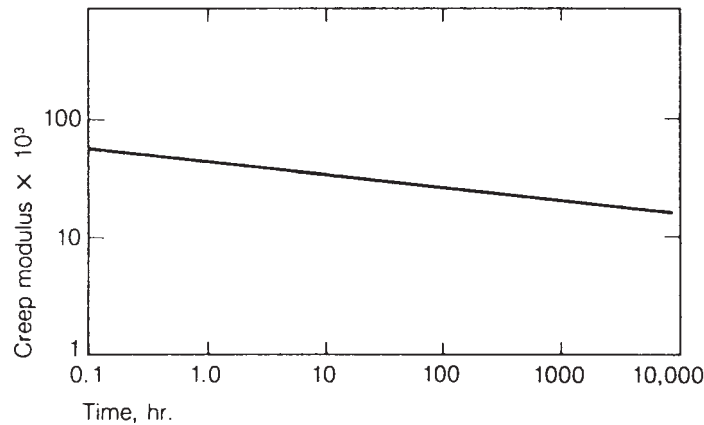**FIG. X2.3 Creep Modulus Versus Time**

FIG. X2.4 Creep Modulus Versus Time on Logarithmic Coordinates

X3. CREEP STRENGTH AND CREEP RUPTURE

X3.1   In reporting strength data, creep strength and rupture strength (creep rupture), is often spoke of.

X3.2   The minimum creep rate (slope d_E/d_t) is one of the important parameters. A condition (for example, for jet-engine material) is the stress needed to produce a creep rate of 0.0001 % E/h or 1 % $E/10\ 000$ h. Fig. X3.1 illustrates the importance of the creep rate.

X3.3   *Creep Strength* is defined as the stress at a given temperature that produces a steady creep rate of a fixed amount in percent per hour. (See Fig. X3.2)

X3.4   *Rupture Strength* is defined as the stress at a given temperature to produce rupture in a fixed amount of time in hours. (See Fig. X3.3)

X3.5   The stress-rupture test is basically similar to a creep test with the exception that it is continued until the material fails. Since higher loads are used, creep rates are higher and the material fails in a shorter time (usually terminated in 1000 h).
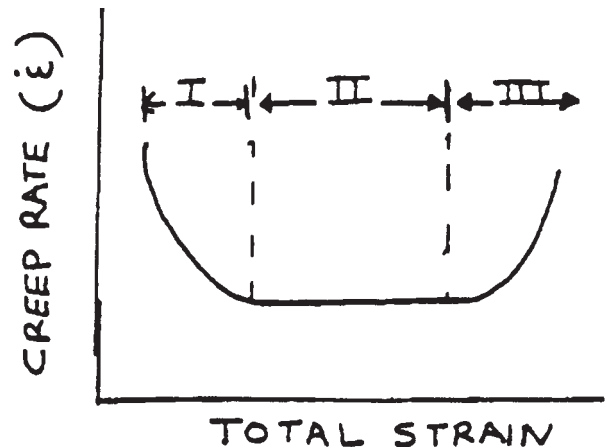
FIG. X3.1 Creep Rate

This test is useful in establishing a safe envelope inside which a creep test can be conducted. The basic information obtained from the stress-rupture test is the time-to-failure at a given

10
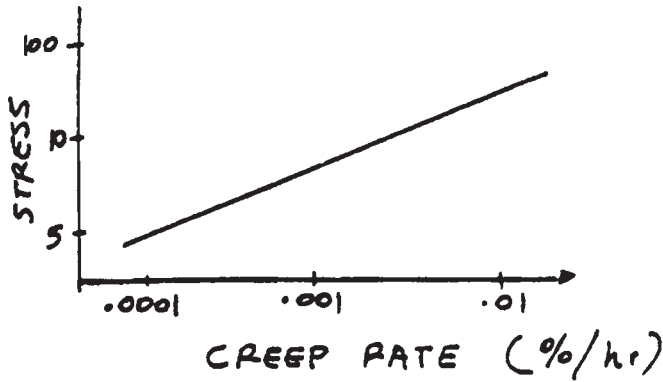
FIG. X3.2 Creep Strength
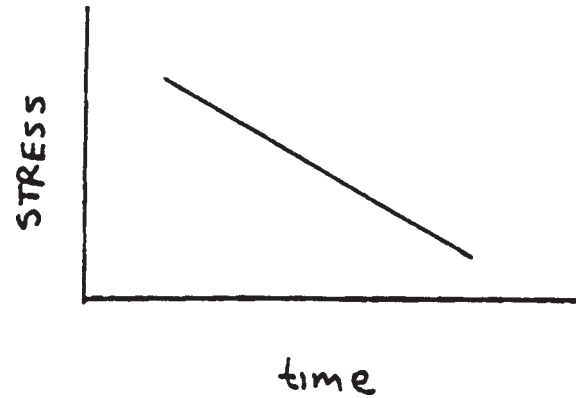
FIG. X3.3 Rupture Strength

stress. Based on this data, a safe stress can be determined below which it is safe to operate, given the time requirements of the end-use application. The construction of the creep rupture envelope is shown in Fig. X3.4. Strain is plotted as a function of time at different stress levels by connecting the rupture points (before establishing the rupture point remember that for ductile materials there is no abrupt failure, in which case the onset of tertiary creep might be more applicable). The rupture envelope can be created (see Fig. X3.4) (within this envelope creep curves can be used to predict long-term behavior).

X3.6 Plotted creep-rupture stresses versus time-to-rupture data can be used directly for design in some cases. (See Fig. X3.5.)

X3.7 Finally, the following should be taken into consideration when making measurements:

X3.7.1 The extension-measuring device (if attached) should be of adequate resolution, and should not distort the specimen in any way.

X3.7.2 The stress should be applied rapidly, smoothly, and reproducibility.

X3.7.3 If a specimen is expected to undergo dimensional changes (humidity effects, post curing, crystallinity changes, and so forth), then the creep experiment should be accompanied by a control experiment at no stress to study the effects, and compensate for the creep data.
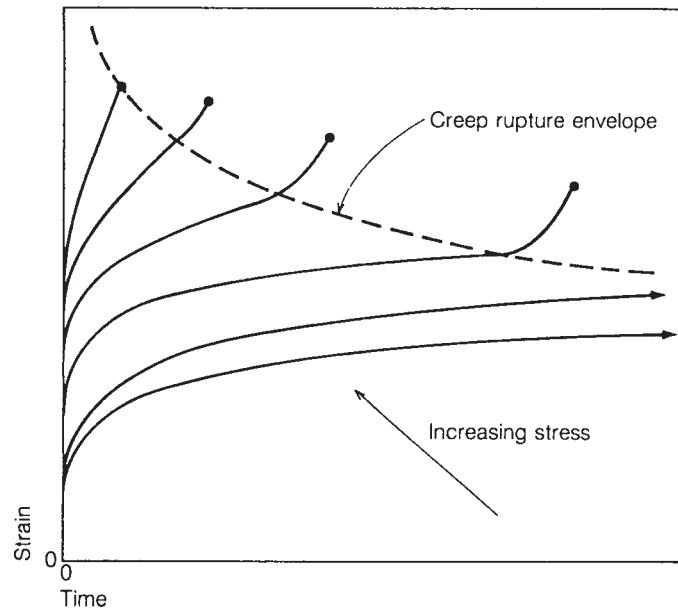
FIG. X3.4 Creep Rupture Envelope

A—SAN at 23° C.
B—Epoxy MC at 120° C.
C—30% glass-reinforced nylon (dry) at 120° C.
D—30% glass-reinforced PBT at 150° C.
E—Mineral-filled phenolic MC at 120° C.
F—Acetal at 80° C.
G—Impact polystyrene at 23° C.
H—Alkyd MC at 120° C.
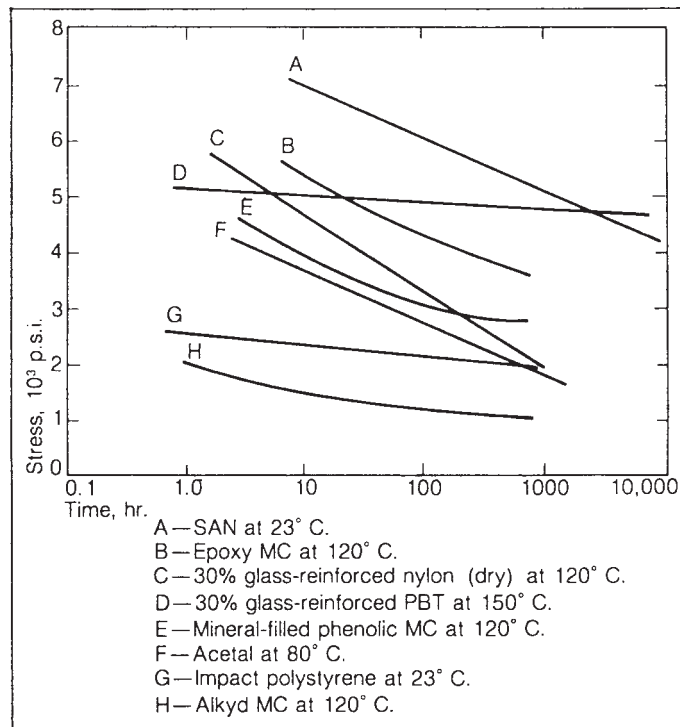
Note—Like creep-rupture curves, creep-modulus data can be obtained by dividing the stress by the measured strain. These values of secant modulus can be used when modulus is required for design purposes.

FIG. X3.5 Creep Rupture Stress Versus Time for Various Plastics

X4. DATA PRESENTATION

X4.1 Creep curves can be presented in a comprehensive way, in constant stress-strain-time coordinates, as shown in Fig. X4.1.

X4.2 From a set of creep curves at various stresses it is possible to construct isochronous stress-strain curves by drawing lines at fixed times (0, 1, 10, 100 h). The resulting curves are the isochronous stress-strain plots. Alternatively, one can start with the isochronous curves and create the creep curves.

X4.3 *The Isochronous Experiment*:

X4.3.1 A stress, σ, (below the yield stress) is applied for an arbitrary time period t (at least ten times the loading period) and the strain at time t is measured.

X4.3.2 The stress is then removed for a period of $4t$ and then a stress $\sigma_1 (\sigma_1 > \sigma_0)$ is applied for another period t. The total strain is measured.

X4.3.3 This procedure is repeated until a stress σ_n is reached. For each stress the strain is measured (see Fig. X4.2).

NOTE X4.1—As the stresses are increased, full-strain recovery after the $4t$ period may not be complete. In this case the additional strain should be recorded. This is defined as the difference between the total strain at the end of the creep period and the residual strain that exists at the beginning of that period.

X4.3.4 The applied stress is then plotted against the additional strain it produces in time t. This curve is the isochronous stress-strain plot and it is used in determining the strain that corresponds to a particular stress at time t.

X4.3.5 Creep curves can be adjusted to correspond to the isochronous data at time t and interpolated for other stresses in correspondence to the isochronous data. Figs. X4.3-X4.5 illustrate this process.

X4.3.6 A quick isochronous test (at stress σ lower than the actual creep stress) is recommended before a long-term creep test begins, to ensure proper specimen-extensometer-machine interaction. Also, when creep tests are conducted, an additional creep is available since the strains at time t should correspond to those of the isochronous experiment.
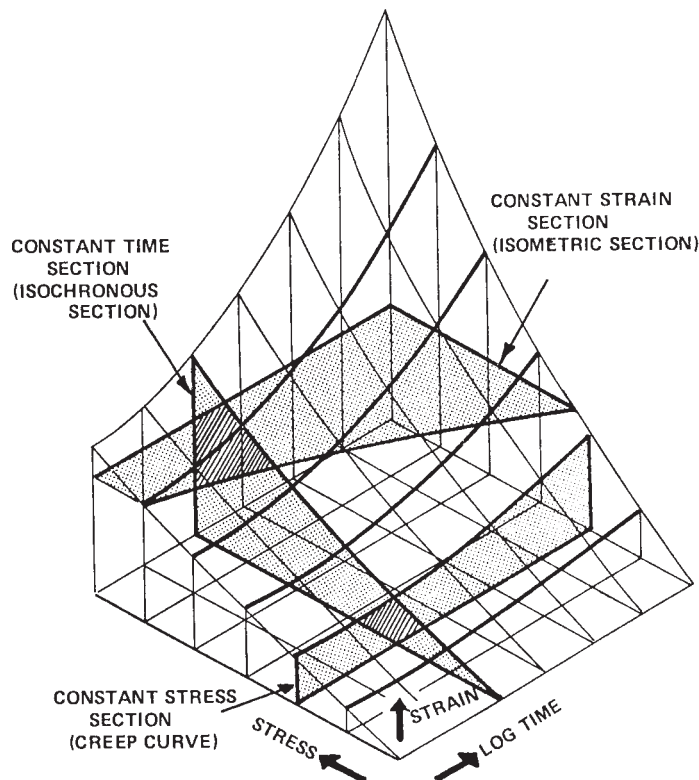

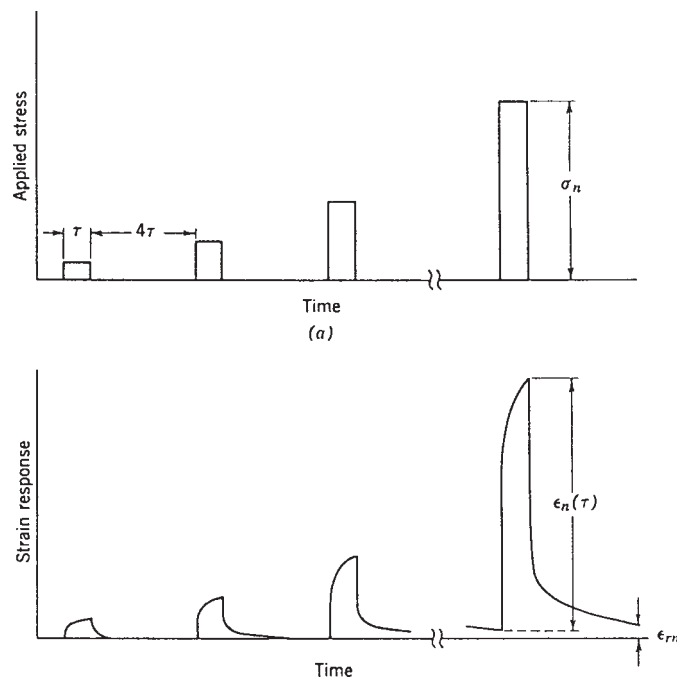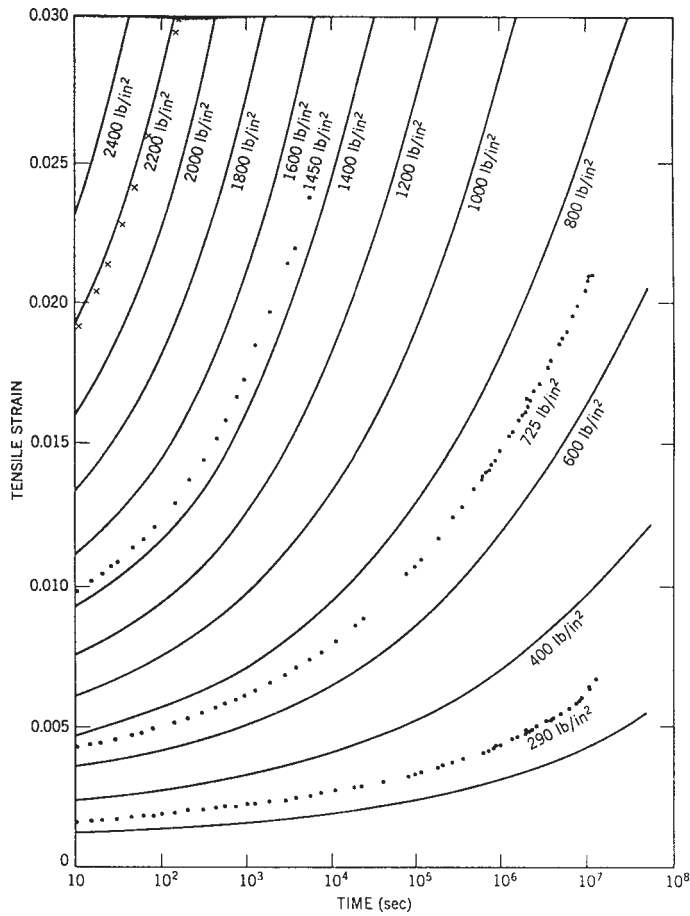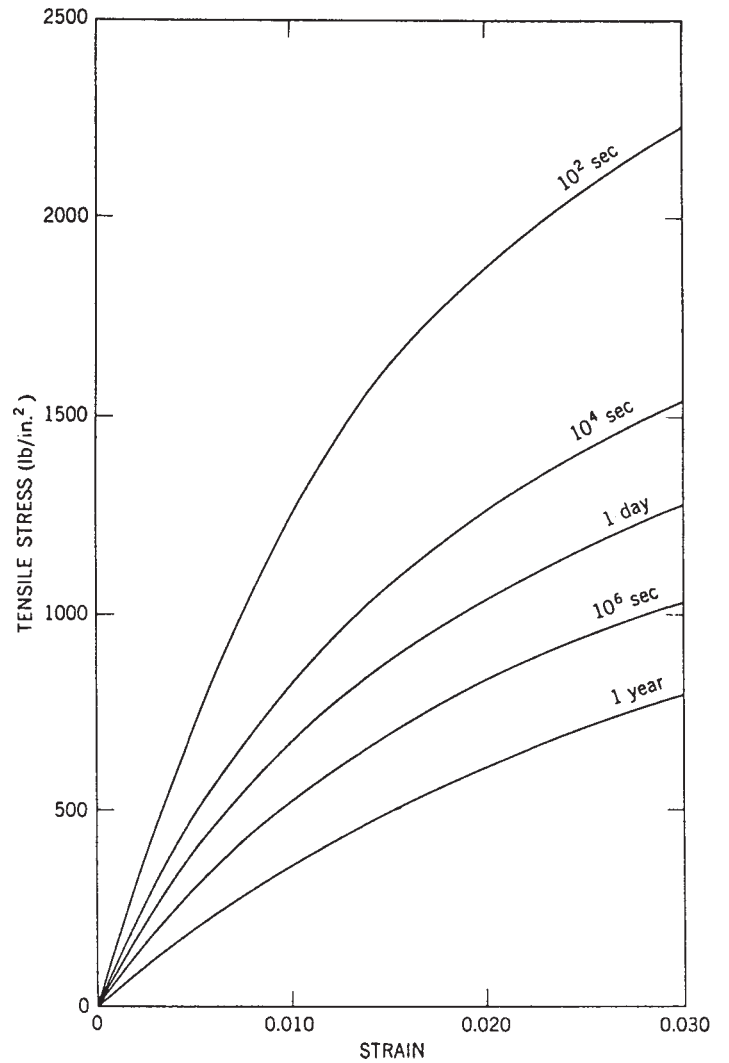FIG. X4.1 Constant Stress-Strain-Time Coordinates

FIG. X4.2 Isochronous Data

NOTE—Propylene-ethylene copolymer at 20°C. (X) for a stress of 2175 lb/in.^{2} (Other experimental creep data are indicated (•). The spacing of 100 s is determined by the isochronous stress-strain experiment.

FIG. X4.3 Numerically Interpolated Creep Data

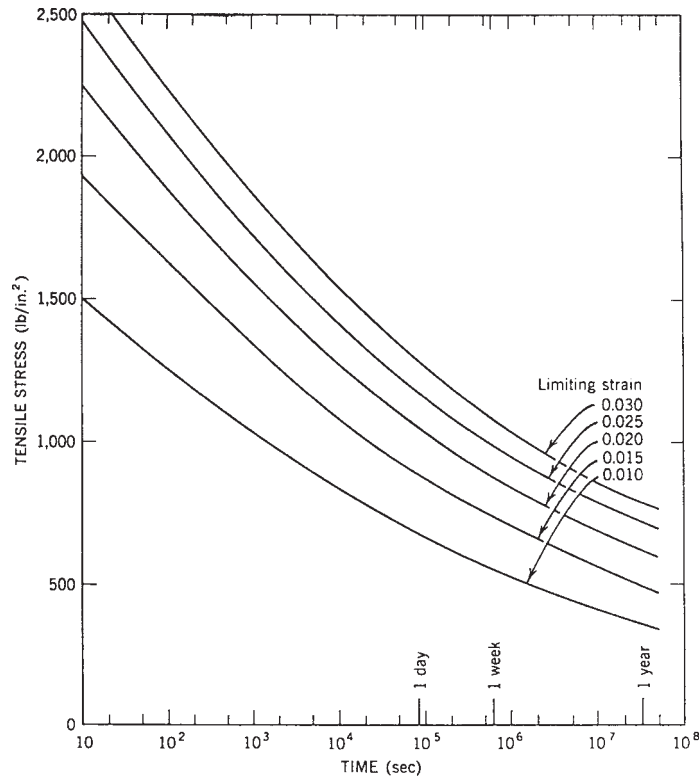**FIG. X4.4 Constant Time Cross Section from Fig. X4.3 (Isochronous Section)**

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FIG. X4.5 Constant Strain Cross Section from Fig. X4.3 (Isometric Sections)

X5. PREDICTION OF LONG-TERM PROPERTIES

X5.1 *Superposition Principles*—Two principles are most often used in the theory of viscoelasticity, the Boltzmann superposition principle and the time-temperature super-position principles.

X5.1.1 The Boltzmann principle describes the response of a material to different loading histories. Treating creep in terms of linear viscoelastic behavior, this principle states the following:

X5.1.1.1 The response of a material to a given load is independent of the response of the material to any load which is already in the material.

X5.1.1.2 The deformation of a specimen is directly proportional to the applied stress, when all deformation are compared at equivalent times. The total strain is given as follows:

$$E(t) = J(t) \sigma_0 + J(t - t_1)(\sigma_1 - \sigma_0) + \ldots J(t - t_n)(\sigma_n - \sigma_{n-1})$$
(X5.1)

where:
J = creep compliance (time-dependent reciprocal of modulus), and
σ_0 = applied stress (initial).

X5.1.1.3 Fig. X5.1 illustrates this principle. The material obeys the power law (Nutting Eq):
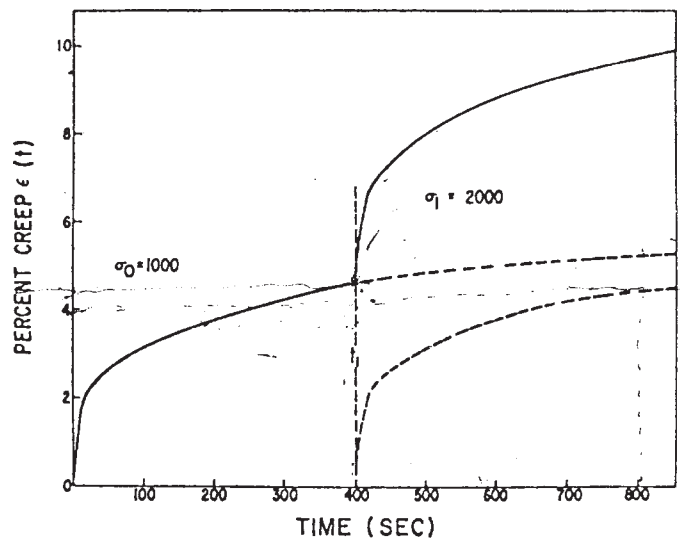
$$E(t) = K\sigma t^n$$
(X5.2)

FIG. X5.1 Boltzmann Principle

where:
K = 10^{-5}, and
n = 0.25 temperature constants.

Doubling the load at 400 s, give a total creep that is the superposition of the original curve shifted by 400 s on top of the extension of the original curve.

X5.1.2 *The Time-Temperature (W-L-F) Superposition Principle*—This describes the equivalence of time and temperature. Creep or relaxation curves made at different temperatures are superposed by horizontal shifts along a logarithmic time scale (W-L-F method, developed by Williams, Landel, and Ferry)[8] to give a single curve covering a large range of times (master curve).

X5.1.2.1 *Construction of a Master Curve*:

X5.1.2.2 Experimental curves are first obtained at a series of temperatures over a specific time period, and the values of compliance or relaxation are plotted. Then the curve at some temperature is chosen as reference (usually Tg). The curves are then shifted one by one along the log time scale until they superimpose. Curves above Tg are shifted to the right, and those below Tg are shifted to the left. A relaxation master curve is shown in Fig. X5.2. Horizontal shift is given as follows:

$$log\ a_T = \frac{17.44\ (T - Tg)}{51.6 + T - T_E} \quad \text{(X5.3)}$$

NOTE X5.1—The numerical values change depending on the reference temperature (°kelvin).

X5.1.2.3 Eq X5.3 holds for most amorphous polymers and it is valid between Tg and 100°C above Tg. Below Tg a different temperature correction should be used.

A W−L−F horizontal factor of

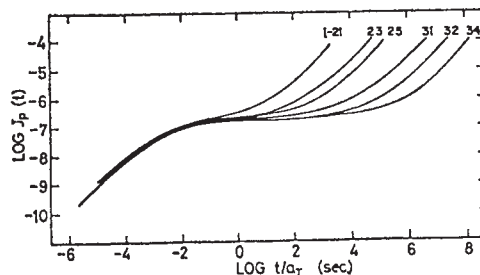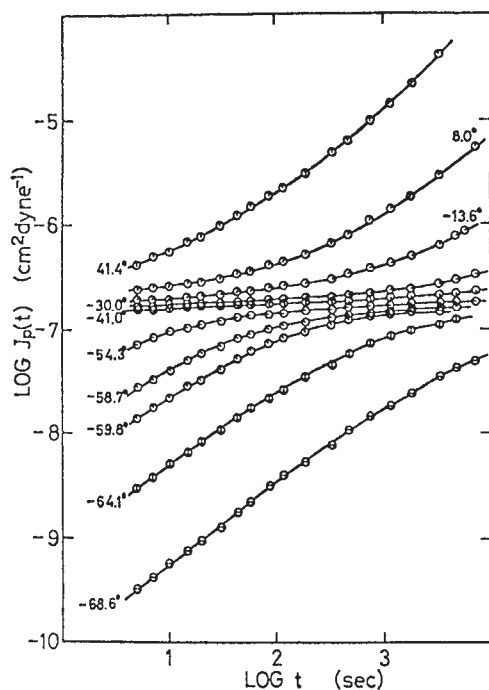$$\log a_T = \frac{-8.90\ (T - T_0)}{89.5 + T - T_0} \quad \text{(X5.4)}$$

is used for the compliance curve shown in Fig. X5.3. The reference temperature $T_0 = -30$°C, 43°C above Tg.

X5.1.2.4 Nielsen,[9] on page 86 of his book, gives a list of references to papers discussing master curves for creep and stress relaxation of various polymers.

X5.1.2.5 Polymers also have a number of retardation times distributed over many decades of time. This distribution $L(t)$ can be estimated from the slope of a compliance curve. Methods for calculating $L(t)$ have been described by Ferry.

---

[8] Nielsen, Lawrence E., *Mechanical Properties of Polymers and Composites*, Vols 1 and 2, Marcel Dekker, Inc., New York, NY, 1974.

[9] *Viscoelastic Properties of Polymers*, 3rd ed., Wiley, NY, 1980.

Creep compliance of polyisoprene at different temperatures. Data are for a fraction with a molecular weight of 1.12 x 10⁶. [Reprinted from Nemoto, et al., Macromol., 4, 215 (1971).]

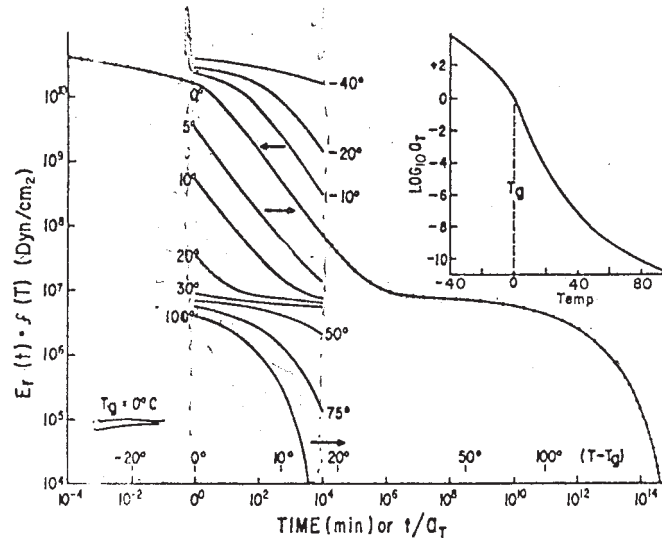Master curves for creep compliance of polyisoprene of different molecular weights at a reference temperature of ~30°C:

Curve Number	M_w
I-21	5.76×10^4
23	1.03×10^5
25	1.59×10^5
31	3.95×10^5
32	6.20×10^5
34	1.12×10^6

[Reprinted from Nemoto, et al., Macromol., 4, 215 (1971).]

FIG. X5.3 Compliance Curve

NOTE—W-L-F time temperature superposition applied to stress relaxation data obtained at several temperatures to obtain a master curve shown by the continuous line. The master curve, made by shifting the data along the horizontal axis by amounts shown in the insert for a_T, is shown with circles on a line.

FIG. X5.2 Relaxation Master Curve

X6. CURVE-FITTING FORMULAS

X6.1 Curve-fitting techniques[10] are used in representing models and extrapolating data for use in engineering design. Creep function are often written as a separable function of stress and time:

$$E = f(\sigma) \times f(t) \tag{X6.1}$$

X6.2 Some of these techniques are summarized in the following equations:
Norton:

$$C = B\sigma^n \tag{X6.2}$$

or

$$\log C = \log B + n \log \sigma \tag{X6.3}$$

where:
C = strain rate,
σ = applied stress, and
B and n = constants of material and temperature.
For secondary creep:

$$C = \frac{E}{t} \text{ and } C = B\sigma^n$$

becomes:

$$E = Bt\sigma^n \text{ or } \log E = \log t + \log B + n \log \sigma \tag{X6.4}$$

In the case of steady-state creep, Eq X6.2 and Eq X6.3 are the power law and log-log law, respectively.
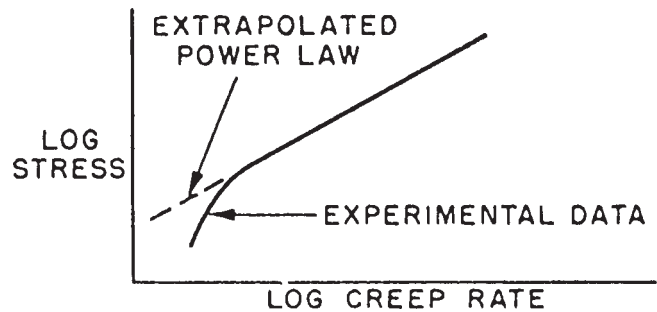
X6.3 *Hyperbolic Sine Creep Law (Nadai)(see Fig. X6.1)*:

[10] Thorkildsen, R.L., "Engineering Design for Plastics," *SPE Series*, Chapter 5, 1964, p. 297.

FIG. X6.1 Hyperbolic Sine Creep Law

$$C = C_0 \sin h \frac{\sigma}{\sigma_0} \tag{X6.5}$$

X6.3.1 Eq X6.5 takes into account the downward trend at low stresses that some materials exhibit, that cannot be predicted by the power law.
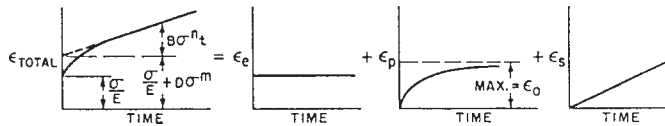
X6.4 *Findley*:

$$e = Kt^n \tag{X6.6}$$

X6.4.1 A function of this form called the time-power law generally will follow Fig. 3 in these test methods. K and n are constants of stress and temperature. A linear dependence on stress, $E = \sigma f(t)$, is well suited to many small deformation problems with solids.

X6.5 A creep curve can be divided into three parts, as shown in Fig. X6.2

number of spring/dashpot components are usually needed to reasonably describe creep or relaxation behavior over decades of time.

NOTE 1—E_e= elastic = σ/E,
E_p= primary = $D\sigma^m (1 - P_e^{-pt})$, and
E_s= secondary = $Bt\sigma^n$.

NOTE 2—Constants P and p, and procedures for deriving them, are given in "Engineering Design for Plastics," *SPE Series*, Chapter 5, 1964, p. 277.

FIG. X6.2 Creep Curve (Three Parts)

X6.6   The four-element model is used to describe both creep and relaxation for several materials (see Fig. X6.3). A large
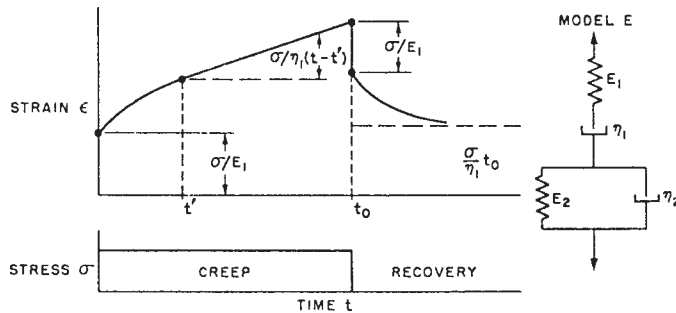
FIG. X6.3 Four Element Model

X7. HOW TO USE THE CREEP CHART TO DESIGN WITH PLASTICS UNDER STATIC LOAD
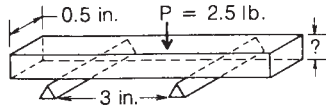
X7.1   See Fig. X7.1 for example problems.

EXAMPLE PROBLEM 1:

Find the minimum depth of a simple rectangular beam of SAN resin that will meet the following design conditions at 23° C. (73° F.):

Support a midspan load of 2.5 lb. for 5 years without fracture and without causing a deflection of the beam greater than 0.1 in. Span = 3 in.; beam width = 0.5 in.

Step 1: Select the design equations.

For strength:

$$S = \frac{3PL}{2\,bd^2}$$

For deflection:

$$E = \frac{PL^3}{48\,\Delta\,\dfrac{bd^3}{12}}$$

where S = maximum fiber stress, p.s.i.
  E = modulus, p.s.i.
  P = load, lb. = 2.5
  L = Span, in. = 3
  b = width of beam, in. = 0.5
  Δ = beam deflection at midspan, in. = maximum 0.1
  d = depth of beam, in. = ?
  Design life = 5 years

Step 2: Plot *creep rupture* and *creep modulus* data from the Creep Chart (see 1983-84 MPE, p. 512) on semi-log and log-log coordinates respectively. Extrapolate where necessary and read the *design stress* and *design modulus* at 5 years as shown in Figs. 1 and 2.

Note: When creep modulus data are available only at stress levels that produce rupture within the *design life* of the part (5 years in this case), estimate the creep modulus curve at the 5-year design stress level (3400 p.s.i. in this case) by extrapolating the linear portion of the creep modulus curves plotted from available data as shown in Fig. 2.

Step 3: Calculate a *working stress* and *working modulus* from the design stress and design modulus derived in Step 2:

Working Stress = Design Stress × Safety Factor (assumed)
  = (3400) (0.5) = 1700 p.s.i.

Working Modulus = Design Modulus × Safety Factor (assumed)
  = (350,000) (0.75) = 262,500 p.s.i.

ASTM, military, or other specification classification	Test specimen[13]			Creep test conditions[13]					Creep test data [1,2,3]								
	Molding method	Type or shape	Dimensions	Type of load	Strain measure	Special specimen conditioning	Test temp., °F.	Initial[1] applied stress, p.s.i.	Creep (apparent) modulus,[3] thousand p.s.i. Calculated from total creep strain[2] or deflection (before rupture and onset of yielding) at the following test times:							Time at latest test point, hr.	Time at rupture[4] or onset of yielding at initial applied stress in air, hr.
									1 hr.	10 hr.	30 hr.	100 hr.	300 hr.	1000 hr.	At latest test point		
	CM	T3	1	T	1		73	4400	500	475	455	425	385	325	250	3500	4390 (rupture)[15]
								4920	500	475	455	425	385	315	290	1705	1410 (rupture)
								5500	490	440	410	355	285		285	309	284 (rupture)
								6030	475	435	400	330			275	190	152 (rupture)
								6460	470	430	395				370	47	55 (rupture)
								6870	460						440	6	4.7 (rupture)

Plot Initial Applied Stress   vs. Time at rupture

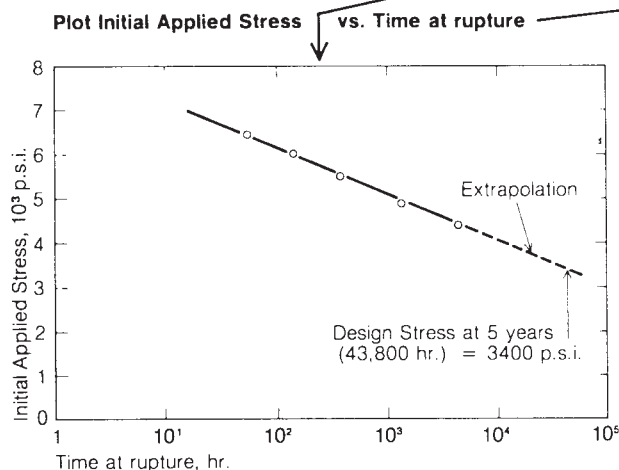**Plot Creep modulus vs. time at each level of Initial Applied Stress**

Fig. 1. Creep rupture of SAN at 73° F., extrapolated to obtain design stress at 5 years.
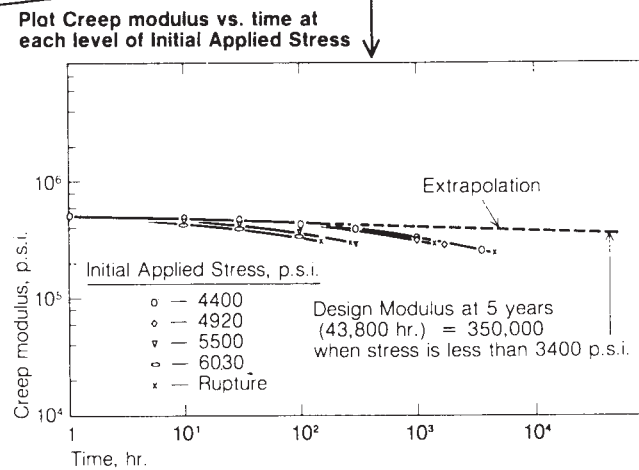
Fig. 2. Creep modulus of SAN at 73° F., extrapolated to obtain design modulus at 5 years.

FIG. X7.1 Example Problems

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Step 4: Calculate the depth of beam required to support the load without fracture:

$$d = \sqrt{\frac{3PL}{2bS}} = \sqrt{\frac{(3)(2.5)(3)}{(2)(0.5)(1700)}} = 0.115 \text{ in.}$$

Step 5: Calculate the deflection of the 0.115-in. beam calculated in Step 4 and compare to the maximum deflection requirement, 0.1 in

$$\Delta = \frac{PL^3}{48E\frac{bd^3}{12}} = \frac{(2.5)(3)^3}{(48)(262,500)\frac{(0.5)(0.115)^3}{12}}$$

$$= 0.08 \text{ in. (less than 0.1 in.)}$$

ANSWER: A beam of 0.115 in. depth will support the design load and meet the maximum deflection requirement at 5 years.

	Test specimen[13]					Creep test conditions[13]				Creep test data [1,2,3]								
										Creep (apparent) modulus,[3] thousand p.s.i.								Time at rupture[4] or onset of yielding at initial stress in air, hr.
											Calculated from total creep strain[2] or deflection (before rupture and onset of yielding at the following test times:						Time at latest test point, hr.	
ASTM, military or other specification classification	Molding method	Type or shape	Dimensions	Type of load	Strain measure	Special specimen conditioning	Test temp., °F.	Initial[1] applied stress, p.s.i.	1 hr.	10 hr.	30 hr.	100 hr.	300 hr.	1000 hr.	At latest test point		
									435 315 285	420 295 265	400 285 260	385 280 250	380 275 240	375 265 230			

EXAMPLE PROBLEM 2:

Calculate the deflection of a simple rectangular beam of 30% glass-reinforced PBT after 1 year at 100° C. (212° F.) under a midspan load of 2.75 lb. The beam width is 0.5 in.; beam depth is 0.090 in.; the span is 4 in.

Step 1: Calculate the maximum fiber stress on the beam.

$$S = \frac{3PL}{2bd^2} = \frac{(3)(2.75)(4)}{(2)(0.5)(0.090)^2} = 4074 \text{ p.s.i.}$$

Step 2: Plot the *creep modulus* data from the Creep Chart (see 1983-1984 MPE, p. 512); extrapolate where necessary, and read the *creep modulus* at 1 year: 310,000 p.s.i.

Note: When creep modulus curves vary significantly with level of Initial Applied Stress, read the creep modulus from the curve having the closest stress level to the *maximum fiber stress* calculated in Step 1.

Step 3: Calculate the deflection after 1 year using the creep modulus derived in Step 2.

$$\Delta = \frac{PL^3}{48E\frac{bd^3}{12}} = \frac{(2.75)(4)^3}{(48)(310,000)\frac{(0.5)(0.090)^3}{12}} = 0.389 \text{ in.}$$

ANSWER: Beam will deflect 0.389 in. after 1 year.

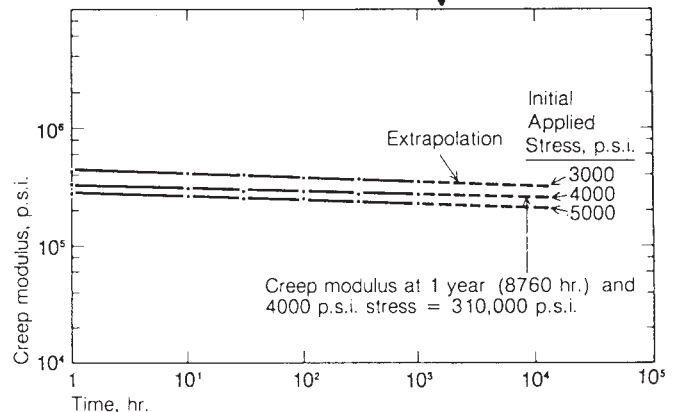Plot Creep modulus vs. time at each level of Initial Applied Stress

Fig. 3. Creep modulus of 30% glass-reinforced PBT at 212° F., extrapolated to obtain the design modulus at 1 year.

FIG. X7.1 *(continued)*

X8. SUMMARY

X8.1 *Summary*:

X8.1.1 Obtaining the necessary data for use in design includes the following:

X8.1.1.1 Measurement of complex modulus as a function of *T*,

X8.1.1.2 Determination of an isochronous stress-strain curve,

X8.1.1.3 Creep tests at stress levels chosen from the isochronous data, and duration to cover the service life of the material,

X8.1.1.4 A control experiment to determine dimensional change,

X8.1.1.5 Repeating X8.1.1.2 and X8.1.1.3 at high temperatures,

X8.1.1.6 Based on the data, apply superposition theories, and

X8.1.1.7 Perform failure analysis.