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14. ABSTRACT

This TOP outlines various tests which can be performed to determine creep data for metals, plastics, fasteners, metal-to-metal adhesives, and continuous fiber-reinforced ceramic composites. A general discussion of creep behavior in materials is presented along with the selection criteria utilized for the various test methods. Common creep test procedures and guidance are provided which includes test equipment requirements, test conduct, data processing, data presentation, and data analysis techniques.

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Stress Analysis	Compression	Rupture

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CREEP TEST PROCEDURES

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1. SCOPE.

1.1 Purpose. This Test Operating Procedure (TOP) outlines the various tests procedures and requirements which can be performed to determine creep data for metals, plastics, fasteners, metal-to-metal adhesives, and continuous fiber-reinforced ceramic composites. Appendix A gives a general discussion of the creep behavior of materials. Appendix B outlines the criteria for selecting a test method for each material and also discusses the applicability of each type of creep test. This TOP instructs personnel in the techniques for conducting creep tests on various materials and the evaluation of the data from these tests.

* This TOP supersedes TOP 5-2-599, dated 31 January 1968.

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2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities.

2.1.1 Materials testing laboratories or facilities as required.

2.1.2 Machine shop facilities as required.

2.2 Instrumentation.

2.2.1 Creep Testing Equipment. The equipment required for conducting creep tests consists primarily of:

a. Loading device(s) or equipment

b. A furnace or heating chamber equipped with sensitive temperature regulating controls

c. An accurate extensometer

d. Time measuring, recording, and supporting instrumentation, and software

2.2.2 Loading Device(s) or Equipment. Most equipment for creep testing is designed as multipurpose tension/compression loading, servo-hydraulic testing system(s) for static and dynamic testing. Specific creep testing equipment is available that meets particular creep testing standards. One type of equipment for creep testing metals is of a standard lever arm design. This loading equipment just applies a dead load to the specimen and does not have the capacity for compensating the load for changes in cross sectional area of the specimen. It is satisfactory for long duration creep testing and for creep testing where total-deformation prior to rupture is small. For short time duration creep tests or for constant stress creep tests, a loading machine with a variable load capacity is required.

2.2.3 Heating Chamber and Temperature Regulating Controls. Creep testing is generally performed in air. However, there might be a need to perform creep testing in a chamber containing an inert atmosphere such as argon or in a vacuum, or in a controlled environment simulating service conditions. But regardless of the testing atmosphere, perhaps the most important item of equipment used in creep testing is the heating chamber and its temperature regulating controls. An insulating cover is placed around the chamber to conserve energy and prevent temperature fluctuations. Temperature is regulated by thermocouples which control the power input to the furnace. See American Standard for Testing and Materials (ASTM) E633[1*]

[*] Superscript numbers correspond to those in Appendix C, References.

for the use of thermocouples in creep and stress-rupture testing to 1000°C (1800°F) in air. The chamber needs to be capable of providing temperatures up to 1000°C.

2.2.4 Extensometers.

a. There are three types of extensometers for creep tests: mechanical, optical, and electrical. Mechanical extensometers consist of two chrome and nickel alloy rods. One end of each rod, at the gauge length extremities, is clamped to the test specimen and the other end of each rod is attached to a dial indicator. To ensure accuracy and aid in the detection of proper specimen alignment, an extensometer should be used on opposite sides of the specimen. The ease and rapidity with which readings may be taken permit quick determination of initial elastic strain without the introduction of errors caused by early plastic strains. This type of extensometer permits the determination of clearly defined plastic and elastic strains.

b. Optical extensometers consist of two telescopes which are sighted through windows in the side of the furnace and aligned with the gauge marks on the specimen. The extension of the specimen is measured by a filar micrometer attached to one of the telescopes. This type of extensometer requires considerable time for setting and reading the micrometer and thus prevents rapid determination of elastic strains or first stage creep strains. This deficiency may lead to giving a high value of initial strain and a low creep value which will compromise the creep test data. However, the primary advantage of the optical extensometer is that extremely small strains may be detected.

c. Electrical extensometers consist of electrical resistance strain gauges attached to the specimen and connected to a recording device which can produce a continuous record of the strain. This type of extensometer is elaborate and accurate, but is limited to use in temperatures below 482°C (900°F).

2.2.5 Equipment for Creep Testing Materials Other Than Metals.

a. The equipment used for creep testing materials other than metals or items made from other non-metallic materials; e.g., plastics, fasteners, adhesives, and composites, is generally the same as that used for creep testing metals. The exception might be the equipment used in the deflection temperature under load test. The apparatus used in the deflection temperature under load test for these other materials are given in the applicable standard.

b. The extensometers used for creep tests of plastics and adhesives are similar to those used in creep tests of metal; however, some minor modifications may be required to account for the greater degree of creep in plastics and adhesives.

c. There are however several important criteria which are of greater concern in creep testing plastics and adhesives than in creep tests of metals. These are humidity control, chemical

environmental control, and isolation of the test specimen from vibration during testing. Slight changes in humidity or the chemical environment may drastically change the physical properties of a plastic. Vibrations may cause severe changes in applied stresses and, thus, compromise the creep test results.

2.3 Test Controls.

Parameter	Tolerance (see NOTE 1)
Loading	± 1 percent (see NOTE 2)
Temperature	(see NOTE 3)
Heating Chamber or Furnace	(see NOTES 4 and 5)
Extensometers	(see NOTE 6)

NOTE 1: Recording devices shall be accurate within one percent of the selected range for the testing system including readout unit, as specified in ASTM E4[2]. When a tolerance value is given on a parameter, choose the measurement method (including measuring device) so that its measuring uncertainty is negligible. In practice, the uncertainty should be less than one third of the tolerance value.

NOTE 2: Accuracy within ± 1 percent at any load within the selected load range of the testing machine as defined in ASTM E4. See ASTM E4 and ASTM E74[3] for the verification of the force testing machines. The most stringent requirement in loading is that the load on the specimen should be as nearly uniaxial as possible to prevent torsion or bending stresses. Some eccentricity can be avoided by using rods or wire cables of greatest possible length to attach the specimen gripping shackles to the heads of the loading machine.

NOTE 3: The necessity for accurate temperature control cannot be over emphasized. Check the applicable standard for the required temperature tolerances. Where creep rates of less than 3×10^{-5} mm (10^{-6} inches) hour are being measured, it is necessary to employ a thermostat within a thermostat. The outer thermostat should control temperature to tighter temperature tolerance.

NOTE 4: The power supply voltage to the heating chamber heater should be controlled to less than one percent variation.

NOTE 5: The ends of the heating chamber should be closed during testing to prevent undesirable temperature fluctuation. It is further necessary that the chamber ends be closed to prevent the escape of an inert gas, when such a gas is introduced into the furnace to preclude oxidation of the test specimen surface.

NOTE 6: See ASTM E83[4] for the verification and classification of extensometers. Precise strain measurements are not as difficult to obtain as is proper temperature control, although for high

quality work, measurements of 2.5 x 10^{-4} mm (10^{-5} inches) or 3.0 x10^{-5} mm (10^{-6} inches) are usually mandatory. More precise work may require even closer measurements.

3. REQUIRED TEST CONDITIONS.

3.1 Prepare for test and test conditions by selecting the method of testing using the criteria described in Appendix B.

3.2 Perform the following in accordance with (IAW) the applicable standard and as required for the individual test to be run.

3.2.1 Prepare the test specimens.

3.2.2 Prepare the testing, control and monitoring equipment.

3.2.3 Instrument the test specimens.

3.2.4 Calibrate the control and measurement instrumentation.

4. TEST PROCEDURES.

4.1 General.

4.1.1 Metals. Creep tests of metals are lengthy tests, but generally are much shorter in duration than the service life of the actual structures on which the test is being conducted; therefore, judicious extrapolation of creep test data is required by the test engineer. For example, if data are extrapolated from creep tests which have not been carried beyond the first stage, there will be excessively high values of predicted creep. Extrapolation of data from tests carried well into the second stage cannot guarantee that the metal will not enter third-stage creep under service conditions.

4.1.2 Plastics. The term plastics as used in this TOP refers to those non-metallic materials which are generally organic compounds, which display non-crystalline structures, and which derive their mechanical properties from bonding forces and/or network entanglements between molecules rather than inter-intracrystalline bonding as in metals. Because these materials are non-crystalline, they are more nearly isotropic, though heterogeneous, structures than metals provided they are not fiber impregnated. The flow mechanism in these compounds, which is molecular in nature, depends on the bonding forces and network entanglements. In some ways, these conditions make the mechanical behavior of these materials simpler than the mechanical behavior of crystalline materials. Measure the linear dimensional changes of plastics IAW ASTM D1042[5] and as required by the applicable standards.

4.1.3 Fasteners. Fasteners in this TOP refer those fasteners made of steel or other materials intended for use at any temperature from cryogenic to the creep range.

4.1.4 Adhesives. Adhesives in this TOP refer to those used between metals (metal-to-metal).

4.1.5 Continuous Fiber-Reinforced Ceramic Composites. In this TOP these composites are intended for creep testing at elevated temperatures.

4.2 Tension Creep Tests. These tests provide procedures for the determination of the amount of deformation of a test specimen under tension loading as a function of time. During creep tension tests the test specimens are subjected to a constant tension loading at a constant temperature and the creep strain is recorded with respect to time. The creep tension tests objective is to precisely measure the rate at which secondary or steady state creep occurs. Increasing the stress or temperature has the effect of increasing the slope of the line; i.e., the amount of deformation in a given time increment.

4.2.1 Metals. Conduct tension creep tests on metals IAW ASTM E21[6], E139[7], E150[8], and/or E151[9].

4.2.2 Plastics. Conduct tension creep tests on plastics IAW ASTM D638[10], D674[11], D759[12], D2990[13], E21, and/or E139.

4.2.3 Fasteners. Conduct tension creep tests on fasteners IAW ASTM A962 / A962M[14].

4.2.4 Adhesives (Metal-to-Metal). Conduct tension creep tests on metal-to-metal adhesives IAW ASTM D1780[15] and D2294[16].

4.2.5 Continuous Fiber-Reinforced Ceramic Composites. Conduct tension creep tests on continuous fiber-reinforced ceramic composites IAW ASTM C1337[17].

4.3 Compression Creep Tests. During these tests, the specimens are loaded in compression instead of tension. The problems in aligning the load to ensure uniaxial loading and to prevent buckling during the test make this type of test extremely difficult to conduct. There is little agreement on specific procedures for conducting this type of test and the wide divergence in available data leaves this test in an unsettled state. This same lack of available data and accepted test procedure is also true for torsion, bending, and pressure creep tests.

4.3.1 Metals. Conduct compression creep test on metals IAW ASTM E209[18].

4.3.2 Plastics.

a. These tests are designed to determine the mechanical properties of rigid organic plastics

when loaded in compression at relatively low uniform rates of straining or loading. Test specimens of standard shape are employed. Conduct compression creep test on metals IAW ASTM D695[19].

b. Plastic Deformation Under Compression Load Tests. These tests are conducted to determine the deformation under compression of rigid molded plastic materials. The data obtained by these tests indicate the ability of rigid plastics in assemblies of conductors, insulators etc., that are held together by bolts or other fastening devices, to withstand compression without yielding and loosening the assembly with time. Conduct deformation under compression load creep tests on plastics IAW ASTM D62l[20] Method A, D674, D695, and/or D759.

4.4 Rupture Creep Tests.

4.4.1 Rupture testing is similar to regular creep testing except that the stresses are higher than in a creep test. Rupture tests are used to determine the time to failure so rupture testing is always done until the specimen fails.

4.4.2 Rupture tests, properly interpreted, provide a measure of the ultimate loading ability of a material as a function of time. Creep tests measure the load-carrying ability for limited deformations; hence, the two tests supplement each other. The tests have proven to be useful because it is possible to correlate the time-for-rupture of materials with minimum creep rate data. They are simpler to perform than regular tension creep tests due to the elimination of the task of measuring strain.

4.4.3 There are two types of creep related rupture tests: creep rupture tests and stress rupture tests. Creep rupture and stress rupture tests are tension tests wherein a specimen is loaded and its time-to-rupture is recorded. In the creep rupture test the amount of creep that has occurred at the point of failure is recorded. The stress rupture test gives the time to rupture at a given stress and temperature. Many specimens are tested at varying stresses and a plot of stress versus time to rupture is made.

4.4.4 Pending the availability of creep data from prolonged tests, the rupture tests provide useful information regarding the validity of the usual extrapolation of creep data from tests of 1000 to 2000 hours duration for prolonged service with limited permissible deformation.

4.4.5 Metals. Conduct time-for-rupture creep tests on metals IAW ASTM E l39. Conduct creep rupture creep tests on metals IAW ASTM E150.

4.4.6 Plastics.

a. Conduct creep rupture tests on plastics IAW ASTM D2990, D6112[21], and/or E139.

b. Time-Fracture Creep Tests. These tests are conducted to determine the ability of rigid plastics to withstand creep and fracture as a result of sustained loads. The tests are performed to 1000 hours duration. Elevated temperatures are not a test requirement but the test temperature is generally held at 23 ± 1°C (73.5 ± 2°F) at a relative humidity of 50 ± 2 percent. Conduct time-fracture creep tests on plastics IAW ASTM D694[22].

4.4.7 Fasteners. Conduct rupture creep tests on fasteners IAW ASTM A962 / A962M and/or National Aerospace Standard Metric (NASM) 1312-10[23].

4.4.8 Adhesives (Metal-to-Metal). Conduct rupture creep tests on metal-to-metal adhesives IAW ASTM D1780 and D2294.

4.4.9 Continuous Fiber-Reinforced Ceramic Composites. Conduct creep rupture tests on continuous fiber-reinforced ceramic composites IAW ASTM C1337.

4.5 Plastic Deflection Temperature Under Load Tests. This test is designed to determine the temperature at which an arbitrary deformation occurs when the specimen is subjected to arbitrarily pre-determined test conditions. The data resulting from this test may be used to predict the behavior of plastics at elevated temperatures when time, temperature, loading methods, and stress of the plastic parts in question are similar to those specified in the test. The test specimen is immersed in a liquid heat transfer medium and supported as a simply supported beam with a load applied at midspan. The liquid heat transfer medium must not affect the chemical properties of the specimen in any manner. The temperature increase rate is 1.8 ± 0.1°C (3.6 ± 0.36°F) per minute until the desired temperature is obtained. Conduct deflection temperature under load creep tests on plastics IAW ASTM D648[24]; the special loading device and heat transfer tank used for this test are fully described in this standard.

4.6 Stress Relaxation Tests. In the relaxation tests, the decrease of stress with time is measured while the total strain (elastic + plastic) is maintained constant. The extremely time-consuming nature of these procedures makes them generally unsuitable for routine testing.

4.6.1 Metals. These tests have direct application to the loosening of turbine bolts and to similar problems; however, they do not provide insight into factors influencing fracture. Conduct stress-relaxation tests on metals IAW ASTM E328[25].

4.6.2 Plastics. Conduct stress-relaxation tests on plastics IAW ASTM D674, D2991[26], and/or E328. Stress relaxation tests are conducted on plastics, resisting long-duration constant tension or compression strains at conditions of constant temperature, relative humidity, and negligible vibration.

4.6.3 Fasteners. Conduct stress relaxation tests on fasteners IAW ASTM A962 / A962M and/or NASM 1312-17[27].

4.7 Short Time Creep Tests. When time is a factor, these tests have been used to obtain rapid evaluation of different materials. They are not considered the best methods for obtaining reliable data for making material selections and are not considered adequate for the prediction of long time strength in metals.

4.7.1 Metals. Conduct short time creep tests on metals IAW ASTM E21 and/or E150. NOTE: ASTM E2l tests are applicable to metals which are highly resistant to creep and which are to be used at moderately high temperatures but which are lower than the equicohesive temperatures for those metals and, yet, where strength characteristics as well as creep characteristics, are important.

4.7.2 Plastics. Conduct short time creep tests on plastics IAW ASTM E21.

5. DATA REQUIRED.

5.1 There are certain common physical property measurements associated with creep tests of metals, plastics, fasteners, metal-to-metal adhesives, and continuous fiber-reinforced ceramic composites. These are creep, creep rate, recovery, and time-to-rupture. Measurements pertinent to creep tests of plastics, but not necessarily pertinent to creep tests of metals are instantaneous creep and instantaneous recovery. Instantaneous creep is the creep measured as close to the time of load application as possible. Instantaneous recovery is the recovery measured as close to the time of load release as possible. All dimensional measurements taken during creep testing on plastics shall follow the criteria of ASTM D694.

5.2 Record, describe, and state all the following data or test conditions as applicable for the given material or item. Address specific data requirements IAW the relevant standards and/or definitions.

5.2.1 Part / Specimen Material Data. This includes part/specimen number or product identification, description traceable back to manufacture (e.g., lot identification), material (type, alloy, chemical composition), metal heat treatment and hardness, part/specimen configuration/dimensions (reduced or adjusted length, width, diameter, as applicable), dimension between gage markers, and of type of surface (machined, as cast, as rolled).

5.2.2 Standard Identification and Test Method (e.g., applicable ASTM or NASM standard and/or test method number).

5.2.3 Test Equipment Data. This includes model, serial number, capacity, calibration date, installation procedure, and weights and lever ratio if lever arm type equipment is used.

5.2.4 Extensometer Data. This includes the make and class identifying number, latest calibration report, attachment location on reduced section or on shoulders, distance between and

location of attachment points (reduced section, shoulders, or holders), gage length used (if not attached to reduced section), and method of correcting for fillet strain if the extensometer was not attached to the reduced section of the specimen.

5.2.5 Temperature Equipment Data. This includes temperature measuring instrument make and model, and temperature controller make and model.

5.2.6 Thermocouple Data. This includes type, material, and number of thermocouples, wire size, attachment technique, shielding, and calibration.

5.2.7 Test Temperature / Environmental Data. This includes test temperature in °C (°F), test temperature readings (total number, minimum, maximum, and duration of each), average ambient temperature during the test duration, average percent relative humidity for plastics during test duration, temperature/relative humidity excursions greater than allowable limits, and media other than air used at atmospheric pressure surrounding the specimen.

5.2.8 Load / Stress Data. This includes tension or compression test load, loading methods, stress (σ) in MPa (ksi), rate of force application and removal, final load / stress, and residual load / stress; note that during an increase in strain with the increase in stress during step force application an estimate of the elastic modulus can be calculated and any abnormal behavior of the test stand and extensometers can be readily observed.

5.2.9 Strain (Deformation) / Creep Data. This includes strain vs time, required strain or strain rate (E), total strain on application of force, total plastic strain, initial creep (E_0), total creep (E_p), creep rate (E_c), minimum creep rate (percent) per hour, second stage (steady state) creep rate, third stage creep rate, and strain at intercept of the tangent at minimum creep rate with the strain axis at zero time (Cartesian coordinates).

a. Strain measurements will be in elongation (percent) or in reduction of area (percent); measurements will be based on the gage length or elongation (percent) from shoulder measurements, or based on the adjusted gage length; reduction of area (percent) is usually used for specimens of circular cross section.

b. For rupture tests data: amount of creep at the point of failure, maximum extension in percent elongation or percent of reduction of area, type of failure, the location and description of fracture particularly if outside gauge marks or center area of reduced section; for tests halted before rupture, elastic contraction when the force was removed.

5.2.10 Time (t) / Test Duration Data. This includes time measurements vs stress, vs strain, at temperature, time-to-failure or rupture (tr), time at the start of second and third stage creep and at the end of second and third stage creep, time at which force was removed during the test, and interruptions during test.

a. Time to nearest 0.1 hour for test durations of 100 hours or less and to nearest one hour for test durations over 100 hours at the termination of the test.

b. Time measurements to nearest one hour for strains occurring at over 100 hours for those of the following total strains included in the tested range, 0.1, 0.2, 0.5, 1.0, 2.0, and 5.0 percent.

c. Time at temperature before force application, and if possible, the time to reach test temperature and soak time.

d. Cause and length of interruption during test.

5.2.11 Stress Relaxation Test Data. This includes stress vs time, total strain, initial stress and strain, final stress and strain, and for plastics: tension or compression strain, temperature, and relative humidity.

5.2.12 Plastics Deflection Temperature Under Load Test Data. This includes temperature deformation, time, temperature, loading methods, stress, and description of heat transfer medium, special loading device, and heat transfer tank.

5.2.13 Other Data. This includes deviations from the recommended method or unusual circumstances not specified by the method.

6. PRESENTATION OF DATA.

6.1 Plots (Graphs). The results of the creep test can be presented in several ways. The manner in which they are presented will depend on the reason for running the creep test. Creep test data are usually presented as plots (graphs or curves) of strain vs time or stress vs time-to-rupture. Appendix A has some examples of typical creep plots.

6.2 Extrapolating Creep Data.

a. Because of the length of time required to conduct these tests, few creep tests are rerun and often the tests are not conducted over long enough periods of time. These two situations often give rise to the need for extrapolating which may not be valid if the data being extrapolated have been obtained from a test of too short duration or if the data are from the secondary stage of a creep curve that may be approaching the inflection point prior to entering third stage creep. Determine stress levels and extrapolate creep data IAW the applicable ASTM standard.

b. The methods of data presentation for creep tests of plastics are the same as those for metals. The times to rupture for plastics, however, are much shorter than those for metals and complete creep histories for plastics are easier to achieve. Because of this, extrapolation of creep test data for plastics is seldom necessary.

c. There are formulae to fit creep data curves and aid in extrapolating data. It should be realized that these formulae, at best, are empirical methods and are to be used prudently. A brief discussion of these formulae for creep data extrapolation is presented in following paragraphs.

d. The following equation may be used to extrapolate creep for times greater than those shown by a creep data curve, if the following conditions exist:

1) The values of V_0 (strain vs time slope) must be reliable.

2) The time interval for E (strain) must be less than that which would induce third stage creep.

3) The material must show idealized creep, as displayed in Appendix A, Figure A-l.

The equation: $E = E_0 V_0 t$

Where: E = required strain

E_0 = initial creep (Refer to Figure A-1)

V_0 = slope of strain versus time curve during secondary stage

t = time

e. The following expression may be used to extrapolate creep data where steady state creep constitutes most of the strain and elastic strains are neglected (this equation is most commonly used in literature for the calculation of creep):

$$E = B\,\sigma^n$$

Where: E = strain rate

B and n = constants obtained from creep test data

σ = applied stress

f. The most straightforward method for extrapolating stress vs rupture is to compile data for as long a time period as possible then boldly extrapolate. A straight line or best fit curve is usually obtained at each temperature of interest. This information can then be used to extrapolate time to failure for longer times. Changes in slope of the stress rupture line are due to structural changes in the material. It is significant to be aware of these changes in material behavior, because they could result in large errors when extrapolating the data. Since this is

difficult due to unpredictable changes which the curves could have shown had longer time periods been used, an attempt has been made to correlate the effects of temperature (T) and time-to-rupture (tr). Various parameters involving T and tr have been formulated and extrapolated and are based upon a plot of the (T, tr) parameter as a function of stress. The more useful of these parameters is the Larson-Miller parameter (LMP).

$$LMP=T(C-\log E_c) \text{ or } T(C + \log tr)$$

Where: T = temperature in degrees Kelvin

E_c= creep rate

C = a constant obtained by plotting 1/T vs tr at constant stress where tr is expressed in hours; C is approximately equal to 20 when the temperature is expressed in degrees Kelvin

6.3 Creep Data Callout.

a. Creep Tension / Compression Data. The results would be presented as the amount of strain (deformation), generally expressed as a percentage, produced by applying a specified load for a specified time and temperature; e.g., one percent strain in 100,000 hours at 35 N/mm^2 and 475°C.

b. Creep Rupture Data. Creep rupture test results would be expressed as percent strain, time and temperature; e.g.,. rupture occurs at two percent strain at 450°C in 85,000 hours.

c. Stress Rupture Data. Stress rupture test results would be expressed; e.g., 45 N/mm^2 will cause failure at 450°C in 7,000 hours.

APPENDIX A. CREEP TESTING BACKGROUND INFORMATION

1. BACKGROUND.

1.1 The deterioration of materials may assume many forms that arise from various causes. Thus, the physical properties of materials may change due to changes in structure, such as those caused by overaging. Progressive deformation of materials may occur due to fatigue from the repeated application of cyclic stresses. Further, materials may creep objectionably from exposure to relatively high temperatures when under stress, and they may deteriorate progressively, when under load, due to the propagation of defects that were present originally.

1.2 Creep is the name given to the phenomenon of slow deformation of solid materials, over an extended period of time, while being subjected to a load.

1.3 Data from creep tests is of considerable importance in predicting the strength of materials for resisting loads continuously applied for long periods of time and in predicting dimensional changes which may occur as a result of long continued constant loads, particularly at elevated temperatures.

2. CREEP BEHAVIOR.

2.1 The creep behavior of materials has been studied for many years from both the theoretical and applied viewpoints. In general, these studies have been directed toward understanding the effects of material variables, such as composition, grain size, fabrication, and the effects of service variables (such as stress and temperature). The theory of creep is incomplete.

2.2 Creep is the changing of shape of materials (plastic flow) while a continuously applied force is acting on the material. At low temperatures creep rate is usually low and strain is often found to vary as the logarithm of time. The effect of creep increases rather rapidly with an increase in temperature.

3. PROCESS.

3.1 The physical process is comparatively slow, but continuously increasing strain may cause failure in structures due to the breaking of a member or due to structural distortions which exceed design tolerances. Although creep in metals is generally associated with high temperatures, large structures or those structures having close tolerances may be seriously distorted at room temperature by even small non-elastic strains.

3.2 The nature of creep is a complex phenomenon which, in metals, generally advances in three stages as shown in Figure A-l. If a rod-shaped specimen is placed under a dead load in tension at

room temperature at a stress lower than the proportional limit, the strain OA will occur and will remain constant as designated by OAB. If, however, the same stress is applied at an elevated temperature, the strain OC occurs. This strain may be elastic or plastic depending upon the material of the specimen, the temperature, and the stress, but is greater than OA due partly to a lower modulus of elasticity at the higher temperature. The strain continues to increase nonlinearly with time through the primary stage (from C to D) until the second stage is reached. The second stage (from D to E) is characterized by an almost constant increase in strain with time. This is caused by changes in grain structure due to strain hardening. The third stage (from E to F) is characterized by an abrupt change of slope for the strain versus time curve, and strain increases rapidly to the failure of the specimen. During the test, if the stress is removed from the specimen, some of the strain recovers as indicated by the dotted line EH.

Example creep plots are shown in Figures A-2 through A-4.

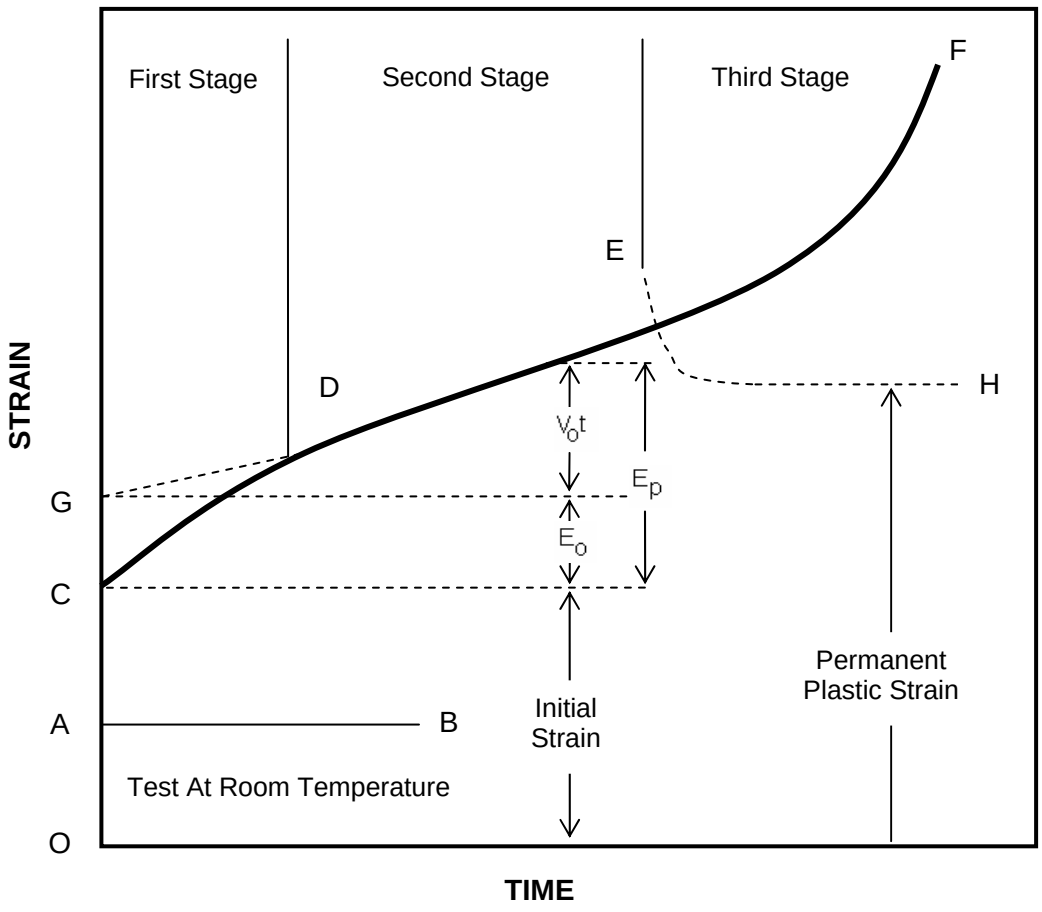

Figure A-1 Strain vs Time

Where:

$V_o t$ = creep rate during second stage

t = total time to second stage

E_o = elementary creep by extending ED to G

$E_p = E_o + V_o t$ = total creep

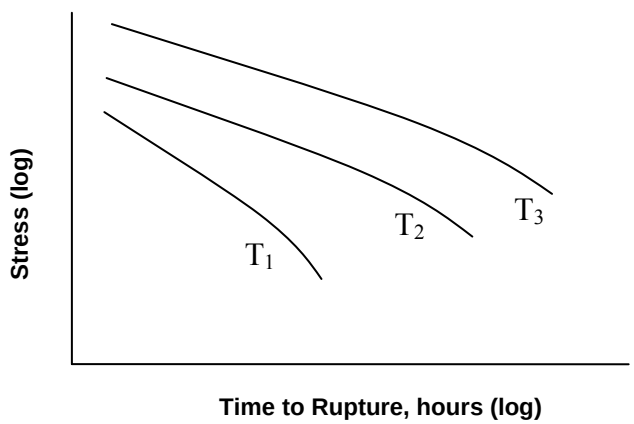

Figure A-2. Typical Stress Rupture Curve at Different Temperatures

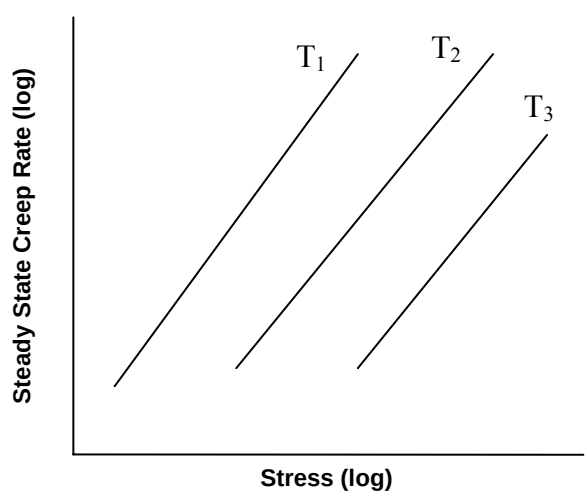

Figure A-3. Minimum Creep Rate vs Applied Stress

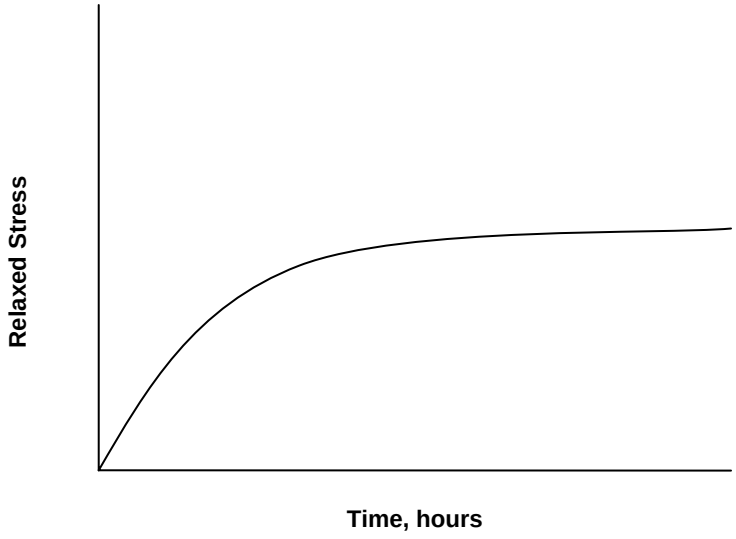

Figure A-4. Typical Stress Relaxation Curve

4. CREEP TESTS. The majority of creep tests are conducted with stress and temperature limits selected so that creep does not progress into the third stage. The failure of metals at low temperatures is characterized by fracture through the crystal boundaries. The temperature at which transition from intra-crystalline to inter-crystalline fracture occurs is referred to as the equicohesive temperature. This temperature varies with each metal and metallic alloy, but as a general rule, the use of a metal or an alloy is limited to a temperature of approximately one-half of its melting point. At temperatures below the equicohesive temperature, strain in metals occurs more as a quasi-viscous inter-crystalline movement. At or below the equicohesive temperature, strain hardening will occur and creep will not continue unless the applied stress is of such magnitude to overcome strain hardening resistance. At temperatures above the equicohesive temperature, yielding will exceed strain hardening and creep will progress under even low applied stresses.

APPENDIX B. CRITERIA FOR CREEP TEST SELECTION

1. SELECTION OF METHOD. The selection of the method for measuring creep in materials is, generally, not a difficult one. The desired results usually are set forth in a test directive and determines to a large extent which method of testing shall be used. However some choice exists, especially where more than one test method can be utilized to generate the necessary data.

2. FACTORS. Factors which affect the choice of the method are:

2.1 Test Material. The type of material to be tested can be assigned to one of the following major categories of testing outlined in this TOP:

a. Metal or metallic material

b. Plastic

c. Fastener

d. Metal-to-metal adhesive

e. Continuous fiber-reinforced ceramic composite

2.2 Material Properties. The mechanical properties of a material must be considered in order to determine the test parameters. Note that creep properties have been well-documented for all common structural materials, especially metals, so creep testing would be redundant in some cases. Sources of information on material properties include:

a. Experimental data

b. Theoretical studies

c. Manufacturer technical literature

d. In-service measurements

2.3 Operational Environments. The expected operational environments determine the selection of material as well as the test parameters. The magnitude of operating temperatures and, therefore, the magnitude of stresses to which the material will be subjected can be predicted and thus the choice of test methods narrowed considerably. Satisfactory tests to determine the material properties at high temperatures are creep tests at those temperatures to which the materials are expected to be subjected. Creep testing is not a definitive process and there is

much to be learned. There are, however, sufficient data available to provide several criteria applicable to creep testing.

2.4 Time Requirements. Since creep tests are classed as both short-time and long-time tests the time requirement becomes important. Generally, short-time tests, if reliably carried out, are less costly and provide data for differentiating between materials. Long-term testing is considered as a source of more reliable data, but if time is a factor, then predications from short-time tests must be utilized. The length of creep test time depends upon a reasonable expectation of the service life of the material being investigated.

2.5 Required Data. Finally the nature of the required data will often determine the ultimate test method. For example, if time-to-fracture must be found for a material, then the choice of tests is further narrowed and combined with other considerations allowing the decision on the test method to be made.

APPENDIX C. REFERENCES

1. ASTM E633, Standard Guide for Use of Thermocouples in Creep and Stress-Rupture Testing to 1800°F (1000°C) in Air.

2. ASTM E4, Standard Practices for Force Verification of Testing Machines.

3. ASTM E74, Standard Practice of Calibration of Force-Measuring Instruments for Verifying the Force Indication of Testing Machines.

4. ASTM E83, Verification and Classification of Extensometers.

5. ASTM D1042, Measuring Change in Linear Dimensions of Plastics.

6. ASTM E21, Short-Time Elevated Temperature Tests of Materials.

7. ASTM El39, Conducting Creep and Time-for-Rupture Tension Tests of Materials.

8. ASTM E150, Conducting Creep and Creep-Rupture Tension Tests of Metallic Materials Under Conditions of Rapid Heating and Short Times.

9. ASTM E151, Tension Tests of Metallic Materials at Elevated Temperatures with Rapid Heating and Conventional or Rapid Strain Rates.

10. ASTM D638, Tests for Tensile Properties of Plastics.

11. ASTM D674, Testing Long Time Creep and Stress Relaxation of Plastics Under Tension or Compression Loads at Various Temperatures.

12. ASTM D759, Tests for Tensile and Compressive Properties of Plastics at Subnormal and Supernormal Temperatures.

13. ASTM D2990, Tensile, Compressive, and Flexural Creep and Creep Rupture of Plastics.

14. ASTM A962/A962M, Standard Specification for Common Requirements for Steel Fasteners or Fastener Materials, or both, Intended for Use at any Temperature from Cryogenic to the Creep Range.

15. ASTM D1780, Adhesives, Metal To Metal, Conducting Creep Tests of.

16. ASTM D2294, Standard Test Method for Creep Properties of Adhesives in Shear by Tension Loading (Metal-to-Metal).

17. ASTM C1337, Standard Test Method for Creep and Creep Rupture of Continuous Fiber-Reinforced Ceramic Composites Under Tensile Loading at Elevated Temperatures.

18. ASTM E209, Compression Tests of Metallic Materials at Elevated Temperatures with Conventional or Rapid Heating Rates and Strain Rates.

19. ASTM D695, Test for Compressive Properties of Rigid Plastics.

20. ASTM D621, Tests for Deformation of Plastics Under Load.

21. ASTM D6112, Compressive and Flexural Creep and Creep Rupture of Plastic.

22. ASTM D694, Testing Long Time Creep and Stress Relaxation of Plastics Under Tension or Compression Loads at Various Temperatures.

23. NASM 1312-10, Fastener Test Methods Method 10 Stress Rupture.

24. ASTM D648, Test for Deflection Temperature of Plastics Under Load.

25. ASTM E328, Standard Test Methods for Stress Relaxation Tests for Materials and Structures.

26. ASTM D2991, Stress-Relaxation of Plastics.

27. NASM 1312-17, Fastener Test Methods Method 17 Stress Relaxation.

For information only (related publications)

a. International Organization for Standardization (ISO) / TTA 5, Code of Practice For Creep / Fatigue Testing of Cracked Components.

b. ISO / DIS 204, Metallic Materials, Uninterrupted Uniaxial Creep Testing in Tension, Method of Test.

c. ISO 899-1, Plastics, Determination of Creep Behavior, Part 1: Tensile Creep.

d. ISO 899-2, Plastics, Determination of Creep Behavior, Part 2: Flexural Creep By Three-Point Loading.

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