Designation: E 139 – 00$^{\epsilon 1}$

Standard Test Methods for Conducting Creep, Creep-Rupture, and Stress-Rupture Tests of Metallic Materials[1]

This standard is issued under the fixed designation E 139; 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.

This standard has been approved for use by agencies of the Department of Defense.

ϵ^1 NOTE—Section 9.2.3 was editorially updated in February 2003.

1. Scope

1.1 These test methods cover the determination of the amount of deformation as a function of time (creep test) and the measurement of the time for fracture to occur when sufficient force is present (rupture test) for materials when under constant tensile forces at constant temperature. It also includes the essential requirements for testing equipment. For information of assistance in determining the desirable number and duration of tests, reference should be made to Section 9.

1.2 These test methods list the information which should be included in reports of tests. The intention is to ensure that all useful and readily available information is transmitted to interested parties. Reports receive special attention for the following reasons: (*1*) results from different, recognized procedures vary significantly; therefore, identification of methods used is important; (*2*) later studies to establish important variables are often hampered by the lack of detailed information in published reports; (*3*) the nature of prolonged tests often makes retest impractical, and at the same time makes it difficult to remain within the recommended variations of some controlled variables. A detailed report permits transmittal of test results without implying a degree of control which was not achieved.

1.3 Tests on notched specimens are not included. These tests are addressed in Practice E 292.

1.4 Tests under conditions of short times are not included. These test methods are addressed in Test Methods E 21.

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

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

2. Referenced Documents

2.1 *ASTM Standards:*

E 4 Practices for Force Verification of Testing Machines[2]

E 6 Terminology Relating to Methods of Mechanical Testing[2]

E 8 Test Methods for Tension Testing of Metallic Materials[2]

E 21 Test Methods for Elevated Temperature Tension Tests of Metallic Materials[2]

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

E 74 Practice for Calibration of Force-Measuring Instruments for Verifying the Force Indication of Testing Machines[2]

E 83 Practice for Verification and Classification of Extensometers[2]

E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods[3]

E 220 Method for Calibration of Thermocouples by Comparison Techniques[4]

E 292 Practice for Conducting Time-for-Rupture Notch Tension Tests of Materials[2]

E 633 Guide for Use of Thermocouples in Creep and Stress Rupture Testing to 1800°F (1000°C) in Air[2]

E 1012 Practice for Verification of Specimen Alignment Under Tensile Loading[2]

2.2 *Military Standard:*

MIL-STD-120 Gage Inspection[5]

2.3 *ASTM Adjuncts:*[6]

Standard unmachined specimens for calibrating creep testing machines (4 by 15⁄16 in. square bar)

3. Terminology

3.1 *Definitions*—The definitions of terms relating to creep testing, which appear in Section E of Terminology E 6 shall

[1] This practice is under the jurisdiction of the ASTM Committee E-28 on Mechanical Testing and is the direct responsibility of Subcommittee E28.10 on Effect of Elevated Temperature on Properties.

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[2] *Annual Book of ASTM Standards*, Vol 03.01.

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

[4] *Annual Book of ASTM Standards*, Vol 14.03.

[5] Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

[6] Available from ASTM Headquarters. Order Adjunct: ADJE0139.

apply to the terms used in this practice. For the purpose of this practice only, some of the more general terms are used with the restricted meanings given below.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *axial strain*—the average of the strain measured on opposite sides and equally distant from the specimen axis.

3.2.2 *bending strain*— the difference between the strain at the surface of the specimen and the axial strain. In general it varies from point to point around and along the reduced section of the specimen.

3.2.2.1 *maximum bending strain*—measured at a position along the length of the reduced section of a straight unnotched specimen.

3.2.3 *creep*—the time-dependent strain that occurs after the application of a load which is thereafter maintained constant.

3.2.4 *creep-rupture test*—a test in which progressive specimen deformation and the time for rupture are measured. In general, deformation is much larger than that developed during a creep test.

3.2.5 *creep test*—a test that has the objective of measuring creep and creep rates occurring at stresses usually well below those which would result in fracture during the time of testing. Since the maximum deformation is only a few percent, a sensitive extensometer is required.

3.2.6 *gage length*—the original distance between gage marks made on the specimen for determining elongation after fracture.

3.2.7 *length of the reduced section*—the distance between tangent points of the fillets which bound the reduced section.

3.2.7.1 The adjusted length of the reduced section is greater than the length of the reduced section by an amount calculated to compensate for strain in the fillet region (see 9.2.3).

3.2.8 *plastic strain during loading*—the portion of the strain during loading determined as the offset from the linear portion to the end of a stress-strain curve made during load application. The offset construction is shown in Test Methods E 8.

3.2.9 *reduced section, of the specimen*—the central portion of the length having a cross section smaller than the ends which are gripped. The cross section is uniform within tolerances prescribed in 7.6.

3.2.10 *strain during loading*—the change in strain during the time interval from the start of loading to the instant of full-load application.

3.2.11 *stress-rupture test*—a test in which time for rupture is measured, no deformation measurements being made during the test.

3.2.12 *total plastic strain, at a specified time*— equal to the sum of plastic strain during loading plus creep.

3.2.13 *total strain, at a specified time*—equal to the sum of the strain during loading plus creep.

4. Significance and Use

4.1 Rupture tests, properly interpreted, provide a measure of the ultimate load-carrying ability of a material as a function of time. Creep tests measure the load-carrying ability for limited deformations. The two tests supplement each other in defining the load-carrying ability of a material. In selecting material and designing parts for service at elevated temperatures, the type of test data used will depend on the criterion of load-carrying ability which best defines the service usefulness of the material.

5. Apparatus

5.1 *Testing Machine*:

5.1.1 The accuracy of the testing machine shall be within the permissible variation specified in Practices E 4.

5.1.2 Exercise precaution to ensure that the force on the specimens is applied as axially as possible. Perfect axial alignment is difficult to obtain, especially when the pull rods and extensometer rods pass through packing at the ends of the furnace. However, the machine and grips should be capable of loading a precisely made specimen so that the maximum bending strain does not exceed 10 % of the axial strain, when the calculations are based on strain readings taken at zero force and at the lowest force for which the machine is being qualified.

NOTE 1—This requirement is intended to limit the maximum contribution of the testing apparatus to the bending which occurs during a test. It is recognized that even with qualified apparatus, different tests may have quite different percent bending strains due to chance orientation of a loosely fitted specimen, lack of symmetry of that particular specimen, lateral force from furnace packing, and thermocouple wire, etc.

5.1.2.1 In testing of brittle material, even a bending strain of 10 % may result in lower strength than would be obtained with improved axiality. In these cases, measurements of bending strain on the specimen to be tested may be specifically requested and the permissible magnitude limited to a smaller value.

5.1.2.2 The testing apparatus may be qualified by measurements of axiality made at room temperature. When one is making an evaluation of equipment, the specimen form should be the same as that used during the elevated-temperature tests. The specimen concentricity should be as near perfect as reasonably possible. Only elastic strains should occur throughout the reduced section. This requirement may necessitate use of a material different from that used during the elevated-temperature test.

5.1.2.3 Test Method E 1012, or an equivalent test method **(1,2)**,[7] shall be used for the measurement and calculation of bending strain for round, rectangular, and thin strip specimens.

5.1.2.4 Axiality measurements should be made at room temperature on the assembled machine, pull rods, and grips before use for testing. Gripping devices and pull rods may oxidize, warp, and creep with repeated use at elevated temperatures. Increased bending stresses may result. Therefore, grips and pull rods should be periodically retested for axiality and reworked when necessary.

5.1.3 The testing machine should incorporate means of taking up the extension of the specimen so that the load will be maintained within the limits specified in 5.1.1. The extension of the specimen should not allow the loading system to introduce eccentricity of loading in excess of the limits specified in 5.1.2. The take-up mechanism should avoid

[7] The boldface numbers refer to the References at the end of this standard.

introducing shock loads, overloading due to friction or inertia in the loading system, or apply torque to the specimen.

5.1.4 The testing machine should be erected to secure reasonable freedom from vibration and shock due to external causes. Precautions should be made to minimize the transmission of shock to neighboring test machines and specimens when a specimen fractures.

5.1.5 For high-temperature testing of materials which are readily attacked by their environment (such as oxidation of metal in air), the specimen may be enclosed in a capsule so that it can be tested in a vacuum or inert-gas atmosphere. When such equipment is used, the necessary corrections to obtain true specimen loads must be made. For instance, compensation must be made for differences in pressures inside and outside of the capsule and for any load variation due to sealing-ring friction, bellows or other features.

5.2 *Heating Apparatus*:

5.2.1 The apparatus for and method of heating the specimens should provide the temperature control necessary to satisfy the requirements specified in 9.4.4 without manual adjustments more frequent than once in each 24-h period after load application.

5.2.2 Heating shall be by an electric resistance or radiation furnace with the specimen in air at atmospheric pressure unless other media are specifically agreed upon in advance.

NOTE 2—The media in which the specimens are tested may have a considerable effect on the results of tests. This is particularly true when the properties are influenced by oxidation or corrosion during the test, although other effects can also influence test results.

5.3 *Temperature-Measuring Apparatus* **(3)** :

5.3.1 The method of temperature measurement must be sufficiently sensitive and reliable to ensure that the temperature of the specimen is within the limits specified in 9.4.4.

5.3.2 Temperature should be measured with thermocouples in conjunction with potentiometers or millivoltmeters.

NOTE 3—Such measurements are subject to two types of error. Thermocouple calibration and instrument measuring errors initially introduce uncertainty as to the exact temperature. Secondly both thermocouples and measuring instruments may be subject to variation with time. Common errors encountered in the use of thermocouples to measure temperatures include: calibration error, drift in calibration due to contamination or deterioration with use, lead-wire error, error arising from method of attachment to the specimen, direct radiation of heat to the bead, heat-conduction along thermocouple wires, etc.

5.3.3 Temperature measurements should be made with calibrated thermocouples. Representative thermocouples should be calibrated from each lot of wires used for making base-metal thermocouples. Except for relatively low temperatures of exposure, base-metal thermocouples are subject to error upon reuse unless the depth of immersion and temperature gradients of the initial exposure are reproduced. Consequently base-metal thermocouples should be calibrated by the use of representative thermocouples and actual thermocouples used to measure specimen temperatures should not be calibrated. Base-metal thermocouples also should not be re-used without clipping back to remove wire exposed to the hot zone and rewelding. Any reuse of base-metal thermocouples after relatively low-temperature use without this precaution should be accompanied by recalibration data demonstrating that calibration was not unduly affected by the conditions of exposure.

5.3.3.1 Noble-metal thermocouples are also subject to errors due to contamination, etc., and should be annealed periodically and checked for calibration. Care should be exercised to keep the thermocouples clean prior to exposure and during use at elevated temperatures.

5.3.3.2 Measurement of the drift in calibration of thermocouples during use is difficult. When drift is a problem during tests, a method should be devised to check the readings of the thermocouples on the specimens during the test. For reliable calibration of thermocouples after use, the temperature gradient of the testing furnace must be reproduced during the recalibration.

5.3.4 Temperature-measuring, controlling and recording instruments should be calibrated periodically against a secondary standard, such as a precision potentiometer. Lead-wire error should be checked with the lead wires in place as they normally are used.

5.4 *Extensometer System*:

5.4.1 The sensitivity and accuracy of the strain-measuring equipment should be suitable to define the creep characteristics with the precision required for the application of the data. The sensitivity and accuracy of the extensometer should be made part of the report of test results.

5.4.2 Nonaxiality of loading is usually sufficient to cause significant errors at small strains when strain is measured on only one side of the specimen **(4)**. Therefore, the extensometer should be attached to and indicate strain on opposite sides of the specimen. The reported strain should be the average of the strains on the two sides, either a mechanical or electrical average internal to the instrument or a numerical average of two separate readings.

5.4.3 Whenever possible the extensometer should be attached to the specimen, not to any load carrying parts joined to the specimen, because the intervening joints and parts introduce significant extensions which are not accurately separable from the extension in the specimen alone.

5.4.4 To avoid the inaccuracy introduced by strain in the fillets and shoulders, the extensometer should be attached to the reduced portion of the specimen, whenever this is feasible.

5.4.4.1 However, it is sometimes necessary to attach the extensometer to the specimen shoulders. For example, when materials with low ductility are tested, failure tends to occur at the extensometer attachments unless these are located on the specimen shoulders.

5.4.4.2 When making a creep-rupture test of a ductile material an extensometer attached to the reduced section of a specimen tends to loosen as the cross-sectional area decreases during the test. In this case the extensometer may be attached to the specimen shoulders or to small ribs machined at the ends of the reduced section of the specimen for that purpose **(5)**.

5.4.5 When it is necessary to use miniature specimens, the extensometer may be attached to the specimen holders. The observed values of extension should be adjusted as described in 9.6.3 and 10.2.4. Even with this adjustment the strain values are of inferior accuracy and the reported values should be labeled "approximate." The method of measurement should be described in the report.

5.5 *Room Temperature Control*:

5.5.1 The temperature in the room should be sufficiently constant so the specimen temperature variations do not exceed the limits stated in 9.4.4.

5.5.2 Extensometer readings should be taken only when the room temperature is within ±5°F (3°C) of the room temperature at the time of loading, unless a correction is applied to the extensometer reading. The extensometer correction equation or chart should have specimen temperature as well as room temperature as a variable. The correction may be omitted if it has been established that the extensometer reading is not changed by variations in room temperature. In evaluating the effect of such variations, the electronic instrumentation should also be calibrated at various ambient temperatures.

5.6 *Timing Apparatus*—For rupture testing machines, provide suitable means for measuring the elapsed time between complete application of the load and the time at which fracture of the specimen occurs, to within 1 % of the elapsed time.

6. Sampling

6.1 Unless otherwise specified the following sampling procedures shall be followed:

6.1.1 Samples of the material to provide test specimens shall be taken from such locations as to be representative of the lot from which it was taken.

6.1.2 Samples shall be taken from material in the final condition (temper). One test shall be made on each lot.

6.1.3 A lot shall consist of all material from the same heat, nominal size, and condition (temper).

7. Test Specimen and Sample

7.1 The size and shape of test specimens should be based primarily on the requirements necessary to obtain representative samples of the material being investigated.

7.2 Unless otherwise specified, test specimens shall be oriented such that the axis of the specimen is parallel to the direction of fabrication, and located as follows:

7.2.1 At the center for products 1½ " (38 mm) or less in thickness, diameter, or distance between flats, or

7.2.2 Midway from the center to the surface for products over 1½ " (38 mm) in thickness, diameter, or distance between flats.

7.3 Test specimens of the type, size, and shape described in Test Methods E 8 are generally suitable for tests at elevated temperature with the following modifications: (*1*) tighter dimensional tolerances are recommended in 7.6; (*2*) for creep tests, larger ratios of length to diameter (or width) of reduced section may be desirable to increase the accuracy of strain measurement; and (*3*) for coarse-threaded specimens, made from material with little ductility, the size of thread should be at least ¾ the diameter of the reduced section. According to 7.1, rectangular specimens will be used for sheet and strip. Otherwise, the specimen should have a reduced section of circular cross section. The largest diameter or greatest width specimen consistent with 7.1 should be used except that these dimensions need not be greater than 0.5 in. (12.5 mm).

NOTE 4—Specimen size in itself has little effect on creep and rupture properties provided the material is sound and is not subject to appreciable surface corrosion or orientation effects. A small number of grains in the specimen cross section, or preferred orientation of grains due to fabrication conditions, can have a pronounced effect on the test results. When corrosion oxidation occurs, the results may be a function of specimen size. Likewise, surface preparation of specimens, if affecting results, becomes more important as the specimen size is reduced.

7.4 Specimens of circular cross section should have threaded, shouldered, or other suitable ends for gripping which will meet the requirements of 5.1.2.

NOTE 5—Satisfactory axial alignment may be obtained with precisely machined threaded ends. But at temperatures where oxidation and creep are readily apparent, precisely fitted threads are difficult to maintain and to separate after test. Practical considerations require the use of relatively loose-fitting threads. Other gripping methods have been successfully used **(2, 6)**.

7.5 For rectangular specimens some modifications of the standard specimens described in Test Methods E 8 are usually necessary to permit application of the load to the specimen in the furnace with the axiality specified in 5.1.2. If the material available is sufficient, the use of elongated shoulder ends to permit gripping outside the furnace is the easiest method. When the length of the specimen is necessarily restricted, several methods of gripping may be used as follows:

7.5.1 A device that applies the load through a cylindrical pin in each of the enlarged ends of the specimen. The pin holes should be accurately centered on extensions of the centerline of the gage section. The good axiality of loading of a grip of this type has been demonstrated **(6)**.

7.5.2 High-temperature sheet grips similar to those illustrated in Test Methods E 8 and described as self-adjusting grips have proved satisfactory for testing sheet materials that cannot be tested satisfactorily in the usual type of wedge grips.

7.5.3 Extension tabs may be welded or brazed to the specimen shoulders and extended to grips outside the furnace. When these are used, care must be exercised to maintain coaxiality of the centerlines of the extensions and the gage length. Any brazing or welding should be done in a jig or fixture to maintain accurate alignment of the parts. Any machining should be done after brazing or welding.

7.5.4 Grips that conform to and apply load against the fillets at the ends of the reduced section.

7.6 The diameter (or width) at the ends of the reduced section of the specimen should not be less than the diameter (or width) at the center of the reduced section. It may be desirable to have the diameter (or width) of the reduced section of the specimen slightly smaller at the center than at the ends. The diameter (or width) at the ends of the reduced section shall not be greater than 100.5 % of the diameter (or width) at the center of the reduced section. When specimens of this form are used to test brittle materials, failure may regularly occur at the fillets. In these cases, the center of the reduced section may be made smaller by a gradual taper from the ends and the exception to the requirements above noted in the report. Specimen surfaces shall be smooth and free from undercuts and scratches. Special care should be exercised to minimize disturbance of surface layers by cold work which produces high residual stresses plastic deformation, or other undesired effects. The axis of the reduced section should be straight within ±0.5 % of the diameter. Threads of the specimen should be concentric with this axis within the same tolerance. Other means of gripping should have comparable tolerances.

7.7 For cast-to-size specimens it may not be possible to adhere to the diameter, straightness, and concentricity limitations of 7.6, but every effort should be made to approach these as closely as possible. If the specimen does not meet the requirements specified in 7.6, the test report should so state. The magnitude of the deviations should be reported.

8. Calibration and Standardization

8.1 The following devices should be calibrated against standards traced to the National Institute of Standards and Technology. Applicable ASTM standards are listed beside the device.[8]

Load-measuring system	Practices E 4 and E 74
Extensometer	Practice E 83
Thermocouples[A]	Method E 220
Potentiometers	Method E 220 and STP 470A[B]
Micrometers	MIL-STD-120

[A] Method E 220 melting point methods are also recommended for thermocouple calibration.

8.1.1 Axiality of the loading apparatus should be measured as described in 5.1.2.

8.2 Calibrations and verifications shall be as frequent as is necessary to ensure that the errors for each test are less than the permissible indicated variations listed in these test methods. The maximum period between calibrations and verifications shall be:

Load-measuring system	1 year
Extensometers	1 year[A]
Thermocouples	each lot run
Precision Potentiometers (dry cell type)	1 month
Micrometers and calipers	6 months
Recording systems	6 months
Temperature measuring equipment/system	3 months
Weights	every five years (see 8.4)
Dial Indicators (used to measure creep)	1 month

[A] Extensometers shall be verified for freedom of movement prior to each test.

Exceptions to this list shall be instruments in use when the test exceeds calibration period.

8.3 For verification of creep-rupture testing machines, unmachined blanks of material with predetermined rupture properties are available from ASTM Headquarters at a nominal cost.[6]

8.4 The metal weights used to apply the test force shall be certified every five years (if not painted/plated, or calibrated prior to each test) to be within a limit of error of 0.5 %. Painted/plated weights shall be verified when paint/plating shows wear or damage.

9. Procedure

9.1 *Measurement of Cross-Sectional Area*—Determine the minimum cross-sectional area of the reduced section of the specimen as specified in Measurement of Dimensions of Test Specimens in Test Methods E 8. In addition, measure the largest diameter (or width) in the reduced section and compare with the minimum value to determine whether the requirements of 7.6 are satisfied.

9.2 *Measurement of Original Length*:

9.2.1 Unless otherwise specified, base all values for elongation on a gage length equal to four diameters in the case of round specimens and four times the width in the case of rectangular specimens, the gage length being punched or scribed on the reduced section of the specimen.

NOTE 6—Elongation values of specimens with rectangular cross sections cannot be compared unless all dimensions including the thickness are equal. Therefore, an elongation specification should include the specimen cross-sectional dimensions as well as the gage length. Using a gage length equal to 4.5 times the square root of the cross-sectional area compensates somewhat for variations in specimen thickness but even this does not result in the same value of elongation when specimens of the same material are machined to different thicknesses and tested (**6**).

9.2.2 When the length-to-diameter ratio of the reduced section is greater than standard, the gage length should be approximately one diameter less than the length of the reduced section.

NOTE 7—Recognition must be given to the wide use of total elongation of fractured rupture specimens in judging materials. Percentage elongation is very dependent on the gage length over which it is measured. Adherence to the customary gage length of four times the specimen diameter is, therefore, very desirable. Recognition must be given, however, to the approved use of longer gage length to specimen diameter ratios in rupture testing and the possible objection to gage marks to define the uniform gage length for elongation measurement. Therefore, reporting of elongation for longer gage lengths should be acceptable, provided the gage length is clearly indicated. For most ductile metals a standard four-diameter gage length centered on a fracture occurring in a longer than standard reduced section will give a higher elongation than the standard test. For this reason the use of several, congruent, standard gage lengths to cover a long reduced section is not recommended.

9.2.3 When testing metals of limited ductility gage marks punched or scribed on the reduced section may be undesirable because fracture may occur at the stress concentrations so caused. Then, place gage marks on the shoulders or measure the over-all length of the specimen. Also measure the adjusted length of the reduced section to the nearest 0.01 in. (0.2 mm) as described in 9.2.4. If a gage length, other than that specified in 9.2.1 is employed to measure elongation, describe the gage length in the report. In the case of acceptance tests, any deviation from 9.2.1 must be agreed upon before testing.

9.2.4 When the extensometer is to be attached to the specimen shoulders, measure the adjusted length of the reduced section between points on the two fillets where the diameter (or width) is 1.05 times the diameter (or width) of the reduced section. This dimension is used as the divisor for converting the observed extension to strain in the reduced section (see 10.2.3 and 10.3.1).

9.3 *Cleaning Specimen*—Wash carefully the reduced section and those parts of the specimen which contact the grips in clean alcohol, acetone, or other suitable solvent that will not affect the metal being tested.

9.4 *Temperature Control*:

9.4.1 Form the thermocouple bead in accordance with Guide E 633.

9.4.2 In attaching thermocouples to a specimen, the junction must be kept in intimate contact with the specimen and

[8] *Manual on the Use of Thermocouples in Temperature Measurement*, ASTM STP 470A, ASTM, 1971.

shielded from radiation. Shielding may be omitted if, for a particular furnace and test temperature, the difference in indicated temperature from an unshielded bead and a bead inserted in a hole in the specimen has been shown to be less than one half the variation listed in 9.4.4. The bead should be as small as possible and there should be no shorting of the circuit (such as could occur from twisting the thermocouple wires behind the bead or from a bare attachment wire touching both bare thermocouple wires). Ceramic insulators should be used on the thermocouples in the hot zone. The remaining portions of the wires shall be thermally shielded and electrically insulated by a suitable covering. If some other electrical insulation material is used in the hot zone, it should be carefully checked to determine whether the electrical insulating properties are maintained with higher temperatures.

9.4.3 When the length of the reduced section is less than 2 in. (50 mm) attach at least two thermocouples to the specimen, one near each end of the reduced section. For reduced sections 2 in. or greater, add a third thermocouple near the center.

9.4.4 Before the load is applied and for the duration of the test do not permit the difference between the indicated temperature and the nominal test temperature to exceed the following limits:

Up to and including 1800°F (1000°C)	±3°F (2°C)
Above 1800°F (1000°C)	±5°F (3°C)

9.4.5 The term "indicated temperature" means the temperature that is indicated by the temperature measuring device using good quality pyrometric practice.

NOTE 8—It is recognized that true temperature may vary more than the indicated temperature. The permissible indicated temperature variations in 9.4.4 are not to be construed as minimizing the importance of good pyrometric practice and precise temperature control. All laboratories should keep both indicated and true temperature variations as small as practicable. However, should temperatures vary outside the given limits, time and temperature of the variation shall be recorded and good engineering judgement taken to assure the variations did not affect testing of the material and that the results of the test are valid. It is well recognized, in view of the extreme dependency of strength of materials on temperature, that close temperature control is necessary. The limits prescribed represent ranges that are common practice.

9.4.6 Temperature overshoots during heating should not exceed the limits above. The heating characteristics of the furnace and the temperature control system should be studied to determine the power input, temperature set point, proportioning control adjustment, and control-thermocouple placement necessary to limit transient temperature overshoots. It may be desirable to stabilize the furnace at a temperature from 10 to 50°F below the nominal test temperature before making the final adjustments. Report any temperature overshoot with details of magnitude and duration.

9.4.7 The time of holding at temperature prior to the start of the test should be governed by the time necessary to ensure that the specimen has reached equilibrium and that the temperature can be maintained within the limits specified in 9.4.4. Unless otherwise specified, this time should not be less than 1 h. Record the time to attain test temperature and the time at temperature before loading.

9.4.8 Any disturbance causing the temperature of the specimen to rise above the limits specified in 9.4.4 should be cause for rejection of the test and require retesting. Disturbances causing the temperature of the specimen to fall below the limits specified in 9.4.4 may be cause for rejection of the test and require retesting. Allowing the temperature to fall below the nominal temperature reduces creep rate and prolongs rupture time, both characteristics being very sensitive to test temperature. Low temperatures usually do not damage the material as can over temperature, which may considerably accelerate creep. Consequently under temperature should be cause for retesting only when the time at under temperature significantly alters the test result.

NOTE 9—Cooling and reheating of the specimen under stress can have a significant effect on subsequent creep properties and rupture times. Temperature drops of about 100°F or cooling times of 1 h or greater can reduce rupture times by one-half. Creep properties may be similarly effected. If the stress (force) is removed before the above time or temperature decrease is exceeded, the test can be restarted after the cause for disturbance has been corrected. It has not been determined if a creep test can be restarted. The report shall indicate that the test was interrupted by cooling, length of interruption or decrease, or both in temperature prior to removal of stress, and from what temperature the test was restarted.

9.5 *Connecting Specimen to the Machine*— Take care not to introduce nonaxial forces while installing the specimen. For example, threaded connections should not be turned to the end of the threads or bottomed. If threads are loosely fitted, lightly load the specimen string and manually move it in the transverse direction and leave in the center of its range of motion. If packing is used to seal the furnace, it must not be so tight that the extensometer arms or pull rods are displaced or their movement restricted.

9.6 *Strain Measurement During Test*:

9.6.1 By definition, a creep or a creep-rupture test requires measurements of strain at and following the instant of application of full force. The strain change from zero force to the instant of full force application shall also be recorded (see 9.7.1).

NOTE 10—Incremental strain readings during loading are also of value for the following two reasons: (*1*) the elastic portion of the stressstrain curve during loading may be used to evaluate the operation of the apparatus before the specimen is finally committed; and (*2*) in many applications knowledge of total plastic strain rather than of creep alone is required, therefore the loading curve is necessary. On the other hand, obtaining the loading curve usually requires slower loading than would be used if creep only was measured. This slower loading sometimes results in greater strain at the instant of full-load application than if the load had been applied without the delays caused by incremental loading.

9.6.2 Make strain measurements at sufficiently frequent intervals during a test to adequately define the time-strain (creep) curve. This usually requires more frequent readings during the usual rapid first-stage creep than during second-stage creep. The interval for strain readings should not be more than 24 h or 1 % of the estimated duration of the test, whichever is longer. Omission of readings over weekends or holidays are allowed when the absence of daily readings does not influence the test results.

9.6.3 When the stock size makes it necessary to use a specimen with the reduced section less than 0.25 (6.25 mm) in diameter, the extensometer may be attached to the specimen holders. Then, in order to adjust for the extension which occurs outside the reduced section, it is necessary to test two specimens for each creep curve. One specimen should have the standard proportions, the other specimen should be made shorter by omitting either the reduced section or the reduced section and the fillets. The grip ends and shoulders of both specimens should be similar. Both should be tested with an extensometer attached to the specimen holders (see 10.2.4).

9.6.4 For strain measurement during unloading see 9.7.3.

9.7 *Loading and Unloading Procedure*:

9.7.1 A small fraction of the test force (not more than 10 %) may be applied before and during heating of the specimen. This usually improves the axiality of loading by reducing the displacement of the specimen and load rods due to lateral forces from furnace packing and thermocouple wires (see 9.5). The equivalent extensometer reading at zero force may be obtained by extrapolating the linear portion of the force-extension curve.

9.7.2 Apply the load in a manner that shock loads or overloading due to inertia is avoided. The load may be applied in increments with strain readings between increments to provide stress-strain data for the application of the load. Make the time for applying the load as short as possible within these limitations.

9.7.3 Where total extensions are limited to the same order of magnitude as elastic extensions, it is important to have the elastic portion of the total extension accurately known. In creep tests, this can best be determined by measurement of the instantaneous contraction upon removal of the load at the end of the test.

9.7.4 If a test is interrupted for any reason, the conditions of the resumption of the test shall be recorded in the test report. Exercise care to prevent overloading the test piece due to contraction of the load assembly.

9.8 *Measurements of Specimen After Test:*

9.8.1 For measuring elongation, fit the ends of the fractured specimen together carefully and measure the distance between gage marks or the over-all length to the nearest 0.01 in. (0.2 mm) at room temperature. If any part of the fracture surface extends beyond the middle half of the reduced section of the specimen, the elongation value obtained may not be representative of the material. In the case of an acceptance test, if the elongation meets the minimum requirements specified, no further testing is required; but if the elongation is less than the specified minimum, the test shall be discarded and a retest made.

9.8.2 For measuring reduction of area of specimens of circular cross section, fit the ends of the fractured specimen together carefully and measure the maximum and minimum final diameters and record the average final diameter to the nearest 0.001 in. (0.02 mm) at room temperature. If the fracture occurs at a fillet or gage mark the reduction of area may not be representative of the material. In the case of an acceptance test, if the reduction of area meets the specified minimum, no further testing is required, but if the reduction of area is less than the specified minimum the test shall be discarded and a retest made.

10. Calculation

10.1 *Stress*—Reported stress value is equal to the value of constant axial force applied to the specimen divided by the minimum cross-sectional area measured at room temperature before the test.

10.2 *Strain*:

10.2.1 Calculate strain by dividing the extension by the extensometer gage length measured at room temperature before loading the specimen. The extensions to be used for the various strain measurements are given in their definitions in Section 3. The extensometer gage length to be used depends on the location of attachment points of the extensometer.

10.2.2 If the extensometer is attached to the reduced section of the specimen, the extensometer gage length is the distance between attachment points.

10.2.3 When the extensometer is attached to the specimen shoulders, as is common practice in the case of creep-rupture testing, the measurements recorded include strain at the fillets and shoulder to the point of attachment of the extensometer. It is desirable to apply a correction for this additional strain. When a series of creep tests are made at the same temperature, a correction method similar to that described by Thomas and Carlson **(7)** may be applied. Otherwise, the measured extensions may be divided by the adjusted length of the reduced portion (see 9.2.4). The method used to calculate strain must be clearly stated in the report and be the subject of prior agreement in the case of acceptance testing. Sufficient specimen and extensometer dimensions should be reported to enable the reader to calculate corrections for fillet strain.

Note 11—It is not possible to correct accurately for fillet strain by applying a single, universal factor, as this factor will vary with the stress dependence of the creep rate for any material and test temperature. Fillet corrections were calculated by a method similar to that of Thomas and Carlson **(7)** for a variety of metals which had been tested at various stresses and temperature. For most of these tests, the use of the adjusted length of the reduced portion (described above) gave an error of 3 % or less. In the primary stage of creep, the errors tended to be larger, being 8 % in the extreme case. These values are based on a ratio of length to diameter for the reduced portion of 5. A ratio of 10 would halve the percentage error.

10.2.4 If, in the case of miniature specimens, the extensometer is attached to the specimen holders, the extension for the standard specimen should be reduced by the extension of a specimen without a reduced section, the load and time since loading being the same for both specimens. The difference in extension is then converted to strain in the reduced section by dividing by the length of the reduced section (if the shortened specimen included the fillets) or by the method of 10.2.3 (if the shortened specimen did not include fillets). The test on the shortened specimen may be omitted and the average value of previous tests used if at least three tests on shortened specimens have been made on materials of the same specification, at the same stress and temperature. Whenever the extensometer is not attached to the specimen label the result "approximate" and give the method of measurement in a footnote.

10.3 *Elongation*:

10.3.1 When the gage length is marked on the reduced section of a specimen having a nominally uniform cross-sectional area, the elongation is equal to the gage length after fracture minus the original gage length, the difference expressed as a percentage of the original gage length. If the gage length includes fillets, shoulders, threads, etc., the change in gage length is expressed as a percentage of the adjusted length of the reduced section of the specimen.

10.3.2 A method that can sometimes be used when there is an autographic recording of strain up to the moment of fracture, is to read the elongation as strain offset from the initial, linear, loading line. This can be useful in the case of materials of very low ductility. Since these values are usually lower than those measured from the broken specimen, the method of measurement should be stated with the results.

10.4 *Reduction of Area*—Reduction of area is equal to the minimum cross-sectional area of the reduced section before testing minus the minimum cross-sectional area of the reduced section after testing, the difference expressed as a percentage of the area before testing. Reduction of area is reported only for specimens of circular cross section.

10.5 *Rounding Off*—Unless otherwise specified, for purposes of determining compliance with specified limits, calculated values of elongation and reduction of area shall be rounded off to the nearest 0.5 %, in accordance with the rounding method of Practice E 29.

10.6 *Characteristics of the Creep Curve*:

10.6.1 A plot of creep or total plastic strain *versus* time on Cartesian coordinates is usually constructed. If the curve has a region of decreasing slope followed by a region of increasing slope a line is usually drawn tangent to the curve at the minimum slope. Where the line coincides with the creep curve is called the region of secondary creep. The following results are obtained from the plot:

10.6.1.1 Minimum creep rate,

10.6.1.2 Intercept of tangent line with strain axis at zero time,

10.6.1.3 Time to start of secondary creep, and

10.6.1.4 Time to finish of secondary creep.

10.6.2 In short-time, creep-rupture tests the values of 10.6.1.3 and 10.6.1.4 may not be significantly different. In these cases a tabulation of creep rate at various times and calculations of 10.6.1.2 may give more accurate values than the graphical method and may be substituted for it.

11. Guide for Determining Test Conditions and for Processing Test Data

11.1 The selection of conditions of temperature, stress, and duration of test for specific applications is usually fixed rather rigidly. A large proportion of tests are, however, conducted to provide data defining the general creep and rupture properties. The following paragraphs in this section apply mainly to the latter case with the objective of providing uniform comparative creep and rupture data and aiding in the selection of stresses so that the test results will be close to desired rupture times or minimum creep rates.

11.2 When the tests are carried out to establish load carrying ability to approximately 1000 h, it is desirable to conduct sufficient tests at each test temperature to define curves of initial stress *versus* log time in hours for total deformations of 0.1, 0.2, 0.5, and 1.0 %; such larger deformations up to 5 % as may be of interest or the material can tolerate without rupture; and the stress-rupture time curve. Such plots of properties are commonly known as "design" curves. These curves should extend from the short time of a tension test to the longest time period of interest, with a sufficient number of test points to ensure reliable curves. The values used to define these curves are obtained from creep curves plotted to include the deformation during the application of the load. The creep curves from the rupture tests should be supplemented with sufficient lower-stress creep tests to define the smaller total-deformation curves. The curves of stress *versus* log time for small deformations usually include relatively long straight-line segments. However, there is not an established basis for extrapolating such curves from 1000 h to prolonged time periods without additional data **(8, 9)**. It is considered desirable to show the percentage of elongation with the stress-rupture time data points.

11.3 Creep tests are widely used to obtain a measure of the load-carrying ability of a material for limited deformation in prolonged time periods. Tests are conducted under stresses which will give true minimum creep rates ranging between 0.0001 and 0.00001 %/h (0.1 and 0.01 %/1000 h). Three or more tests at a given temperature should be used to establish a curve of log stress *versus* log creep rate which specifically defines the creep strengths for creep rates of 0.0001 and 0.00001 %/h. Considerable care and judgment should be used to be certain that true minimum creep rates are established.

11.3.1 The log stress-log minimum creep rate curves at several temperatures usually form a family of nearly-parallel straight lines. Consistent families of curves may allow some economy in the number of tests required for each curve. Common practice is to assume that the stress for a creep rate of 0.00001 %/h (0.01 %/1000 h) defines the stress for 1 % creep in 100 000 h. This assumes that all creep occurs at the minimum rate, an assumption which should be checked by estimating total creep **(10)**. Caution should be used to be sure that some peculiarity in the creep characteristics does not result in false indications of minimum creep rate by conducting tests of several thousand hours duration. Many users of such data feel that the creep strength should be verified by tests of 10 000 h or longer duration.

11.4 When plotted to logarithmic scales, data on stress *versus* rupture time for a given temperature usually yield a straight line or one of increasing negative slope. Sometimes the curve is more nearly a straight line when stress on a linear scale is plotted *versus* log rupture time. To establish the curve one or two test points are usually required for each base-10 log cycle of rupture time. Curves that are to be extrapolated should be based on four or more evenly spaced points which cover a log-time range at least three times as great as the extrapolated range. Extrapolation should be limited to one base-10 log cycle.

11.5 Curves of stress *versus*rupture time at several temperatures usually are nearly parallel and form a consistent family of curves. The occurrence of changes in slope for the curves for the higher temperatures within the maximum time of testing is usually indicative of similar slope changes at longer time periods for the curves at lower temperatures. The absence of such changes in slope of curves for the higher-temperature tests lends confidence to the extrapolation in time for the low-temperature curves.

11.6 When the creep and rupture properties are to be defined as functions of temperature, it is recommended that tests be conducted at a sufficient number of temperatures so that curves of properties *versus* temperature can be constructed over the useful temperature range for the material. Usually this requires tests at a minimum of three temperatures.

11.7 No generally accepted methods are available for extrapolating creep and rupture data to temperatures and times beyond the tested range. Considerable use is being made of parameter methods. As experience is gained in using these methods, their limitations will become established and reliability will improve. At their present state of development, parameters are very useful when used with proper precautions.

11.8 The method proposed by Larson and Miller **(10)** takes advantage of the correlation between stress and rupture time usually obtained for tests over a range of temperatures by plotting log initial stress *versus* the parameter $P = (T + 460)(\log t + 20)$, where T is the test temperature in degrees Fahrenheit, and t is the rupture time in hours. In most alloys the data give a quite good correlation by this method. For those materials which do correlate with the Larson-Miller parameter, it is possible to evaluate a relatively wide range of rupture properties with four or more short-time tests. Tests are conducted at a higher temperature to give a parameter covering the time range of interest at lower temperatures. In most cases this procedure will indicate rupture strengths with reasonable reliability. Caution should be used, however, in extrapolating too far time wise due to the parameter correlation tending to vary with time. Secondly the constant 20 in the parameter is an average for many alloys and some error may be introduced by the use of a fixed constant.

11.9 A method proposed by Manson and Haferd **(11)** and Manson and Brown **(12)** relates the log of stress to the parameter $P = (T - T_a)/(\log t - \log t_a)$ where T is the test temperature in degrees Fahrenheit, t is the rupture time in hours, and T_a and $\log t_a$ are constants equal to the coordinates at the intersection of extension of straight lines faired through the rupture test data points plotted as $\log t$ *versus* T for different constant stresses. The recommended rupture time range is from 30 to 300 h. To establish a master curve by the Manson parameter requires more test points than by the Larson-Miller parameter. On the other hand the use of two experimentally determined constants sometimes results in a more accurate prediction of long-time test results by the Manson parameter than by the Larson-Miller parameter.

11.10 When the aim of a creep test is to reach a specified strain in a specified time, the required stress can be estimated from short-time creep tests at higher temperatures by the parameter methods described above. The time for the specified strain is substituted for rupture time in 11.8 or 11.9.

11.11 It is well recognized that creep rates, specific total deformations, and rupture times from individual tests are sensitive to both material and test variables. Consequently care should be exercised in evaluating materials on the basis of those properties. The use of such measures of properties should be accompanied by statistical data showing the reproducibility of test results.

12. Report and Laboratory Record

12.1 For the reasons stated in 1.2, a complete written report of all tests is necessary. Long-time data are particularly expensive and difficult to obtain by testing when needed. Therefore, the results of previous tests are often studied by different people over a period of many years during which equipment and conventional procedure change. To compensate for these changes a detailed report must be available.

12.2 Such values as minimum creep rate and time to rupture can be several times as great for one specimen as for another, even when the specifications for the two specimens are the same. Therefore, the description of the material should be as complete as possible. The report should include as much of the following information as can be obtained.

12.3 *Results from Stress Rupture Tests:* Report the following:

12.3.1 Type of alloy.

12.3.2 Specimen descriptor that will provide traceability back to manufacture.

12.3.3 Product size.

12.3.4 Heat treatment.

12.3.5 Test temperature, °F (°C).

12.3.6 Stress, ksi (MPa).

12.3.7 *Specimen Dimensions*:

12.3.7.1 For circular cross sections—gage diameter, or,

12.3.7.2 For rectangular cross sections—gage width and gage thickness.

12.3.7.3 Length of gage section, 4 × diameter (5 × diameter) or,

12.3.7.4 Length of adjusted gage length (if used), or,

12.3.7.5 Distance between markers on shoulders (if used).

12.3.7.6 Length of reduced section.

12.3.8 Test duration, to nearest 0.1 h for test durations of 100 h or less and to nearest 1.0 h for test durations over 100 h. If test was discontinued then note this in the report.

12.3.9 Maximum extension measured by one of the three following methods and indication of which method is being reported:

12.3.9.1 Elongation (%) based on the gage length, or,

12.3.9.2 Elongation (%) from shoulder measurements and based on the adjusted gage length, or,

12.3.10 Reduction of area (%) for specimens of circular cross section. Note any contribution of surface corrosion to the reduction of area.

12.3.11 The location and description of fracture.

12.4 *The stress rupture behavior of materials can be characterized in the following manner*:

12.4.1 Stress for rupture in times indicated: 1, 10, 100, 1000, 10 000, 100 000 h.

12.5 *Results from Creep Rupture Test*— Report all of the following for creep-rupture tests.

12.5.1 Type of alloy.

12.5.2 Specimen descriptor that will provide traceability back to melting.

12.5.3 Product size.

12.5.4 Heat treatment.

12.5.5 Test temperature, °F (°C).

12.5.6 Stress, ksi (MPa).

12.5.7 *Specimen Dimensions:*

12.5.7.1 For circular cross sections—gage diameter, or,

12.5.7.2 For rectangular cross sections—gage width and gage thickness.

12.5.7.3 Length of gage section, 4 × diameter (5 × diameter) or,

12.5.7.4 Length of reduced section, or,

12.5.7.5 Length of adjusted gage length (if used), or,

12.5.7.6 Distance between markers on shoulders (if used).

12.5.8 Attachment of extensometer, on reduced section or on shoulders.

12.5.9 *Loading data*—The increase in strain with the increase in stress during step loading. An estimate of the elastic modulus can be calculated. Also any abnormal behavior of the test stand and extensometers can be readily observable.

12.5.10 Total strain on loading.

12.5.11 Elastic contraction when the load was removed.

12.5.12 Test duration, to nearest 0.1 h for test durations of 100 h or less and to nearest 1.0 h for test durations over 100 h. If test was discontinued then this shall be noted in report.

12.5.13 Elastic contraction when the load was removed.

12.5.14 The average ambient temperature in the laboratory during the duration of the test.

12.5.15 Average percent relative humidity during test duration.

12.5.16 Temperature excursions greater than allowable limits. Report total number, maximum or minimum temperature recorded, and duration of each.

12.6 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.

12.6.1 *Strain*—A plot on Cartesian coordinates of total strain versus time and a plot of creep versus time on logarithmic coordinates are convenient methods of showing the following items. If tabular presentation is required, the plots may be omitted.

12.6.2 Time to nearest 0.1 h for strains occurring at 100 h and less, to nearest 1.0 h for strains occurring at over 100 h 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 %.

12.6.3 If the test was continued into the tertiary creep stage: (1) minimum creep rate (%) per hour, (2) strain at intercept of the tangent at minimum creep rate with the strain axis at zero time (Cartesian coordinates), (3) time at the start of secondary creep, and (4) time at the end of secondary creep.

12.6.4 Total plastic strain, and time to nearest 0.1 for test durations of 100 h or less and to nearest 1.0 h for test durations over 100 h at the termination of the test.

12.6.5 Method of correcting for fillet strain if the extensometer was not attached to the reduced section of the specimen.

12.7 *Additional Reported Information for Stress Rupture/Creep Rupture/Creep Tests*—Report deviations from the recommended method or unusual circumstances not specified by the method. Examples follow:

12.7.1 Media other than air at atmosphere pressure surrounding the specimen.

12.7.2 Time at temperature before loading, and if possible, the time to reach test temperature and soak time.

12.7.3 Rate of loading and unloading.

12.7.4 Times at which load was removed during the test.

12.7.5 *Values from Isothermal Curves*— When a series of tests at the same temperature is reported, the following items which can be determined without extrapolating more than ten times shall be reported. No extrapolation to shorter times should be made.

12.7.6 Stress for minimum creep rates of 0.01, 0.001, 0.0001, and 0.00001 %/h.

NOTE 12—It is recognized that rarely will all of the information requested in 12.3-12.13.5 be obtained. However, much of these data are readily available and should be included in the report. The data listed are the type of data published in the various *ASTM Special Technical Publications* which summarize the properties of alloys at high temperatures.

12.8 *Additional Information in Laboratory Record*—The following additional information should be retained and made available on request:

12.8.1 The specimen or a record of its disposition,

12.8.2 Chemical composition,

12.8.3 Type of melting used to produce the alloy,

12.8.4 Size of the heat,

12.8.5 Deoxidation practices,

12.8.6 Form and size—bar, sheet, castings, etc.,

12.8.7 Fabrication history of material,

12.8.8 Microstructure,

12.8.9 Grain size,

12.8.10 Hardness, and

12.8.11 Short-time tensile properties at room temperature and at the creep- or rupture-test temperature if available and should include: tensile strength, yield strength for 0.1 % and 0.2 % offset, elongation and reduction in area.

12.9 *Information on Machine*:

12.9.1 Make, model, and capacity of testing machine,

12.9.2 Identifying number, and

12.9.3 Weights and lever ratio used.

12.10 *Extensometer Information*:

12.10.1 Identifying number and latest calibration report, and

12.10.2 Make and class of extensometer, distance between and location of attachment points (reduced section, shoulders, or holders), extensometer gage length used (if not attached to reduced section).

12.11 *Information on Temperature Measuring Equipment*:

12.11.1 Make and model of temperature measuring instrument,

12.11.2 Make and model of temperature controller, and

12.11.3 Number of thermocouples. Thermocouple material, wire size, attachment technique, shielding, and calibration record.

12.12 *Information in the Test Log*:

12.12.1 The frequency and amplitude of temperature cycling before loading,

12.12.2 Date and time of day of each observation of extension and test temperature, and

TABLE 1 Variability of Measured Properties[A]

Reference	Material	Time for Rupture, h	Temp. F (K)	Rupture Time	RA	Elongation	MCR[B]	Time to total strain 0.5 %	1.0 %	2.0 %
(15)	2S[C]	0.1 to 62	900	0.146	0.088	7.0 %[D]				
	Alum.		(755)	(2.6)	(1.7)	(2.6)				
(13)	304[E]	100	1350	11 %	0.041	11.5%	0.073			
	S.S.		(1005)	(1.4)	(1.3)	(1.4)	(1.6)			
	304[F,G]	114	1350	16 %	0.039	15.3 %				
	S.S.		(1005)	(1.6)	(1.3)	(1.6)[D]				
(16)	Nimonic	48 to 1250	1652	0.055	12.9 %	23.4 %		0.127	0.081	0.060
	105[H]		(1173)	(1.4)	(1.4)	(1.9)		(2.3)	(1.7)	(1.5)
(14)	AK4-1[I]	40 to 240	347	0.20[J]						
			(448)	(3.7)						

[A] Upper line is standard deviation, as percent of mean or as logarithm (when underlined). In parentheses on lower line is ratio of quantity measured during two random tests from same batch. Practice E 177 states that this ratio will be exceeded for 5 % of all random pairs.
[B] Minimum creep rate.
[C] Test in one laboratory, no special selection of material indicated.
[D] Average of three stress levels with lives over 17 h.
[E] Tests from same position in the ingot. Material carefully prepared. All tests in one laboratory.
[F] Tests in four laboratories. Material carefully prepared. Average of values from two ingots.
[G] Some of variability may be due to use of different ratios of gage length to diameter in the four laboratories.
[H] Carefully prepared material tested in 20 different laboratories.
[I] Tested in a single laboratory. No special preparation of material indicated.
[J] Scaled from probability plot.

12.12.3 Type of surface (machined, as cast, as rolled).

12.13 *Other Dimensions*:

12.13.1 Fillet radius,

12.13.2 Diameter or width and thickness at shoulders,

12.13.3 Type of grip (threaded, pinned, shouldered, and so forth) and whether machined or as cast, and

12.13.4 Overall length of specimen (if used (not recommended)).

12.13.5 Elongation (%) from overall measurements based on adjusted gage length (not recommended).

13. Precision and Bias

13.1 *Precision*—The precision of the measurement of time for rupture varies with the test conditions such as temperature, material, and stress. It cannot be reduced to a single number. This variation is shown by the values in Table 1 for several conditions that have been extensively tested. Time for rupture, time for a specified strain, and reduction of area were found to be normally distributed when the logarithm of the quantities were plotted. Thus, the expected relationship between two tests of the same batch is defined in terms of the ratios of the times. On the other hand, elongation values were found to be normally distributed without conversion to logarithms. However, the relationship of two tests of the same batch were converted to ratio form in order to be compared directly to the other quantities. The standard deviations were given for the logarithm of the quantity or the quantity itself depending on which measure was originally reported.

13.2 In test method statistical terminology, bias is the difference between an average test value determined by the method and the reference or true test value, usually determined by other, more precise methods of measurement. Reference values, so determined, do not exist for creep and rupture tests since the values of the test properties are a function of the test method. Bias, therefore, cannot be determined.

13.3 The property variation of the materials tested have a greater effect on the measured results than the inaccuracies in the test method **(13, 14)**.

14. Keywords

14.1 creep; creep rate; creep-rupture; elongation; gage diameter; gage length; loading; original cross sectional area; plastic strain; reduction of area; relative humidity; strain; stress; stress rupture; temperature; test time; thermocouples

REFERENCES

(1) *Manual on Use of Thermocouples in Temperature Measurement, ASTM STP 470*, 1970.
(2) Tishler, D. N., and Wells, C. H., "An Improved High-Temperature Extensometer," *Materials Research and Standards*, ASTM, Vol 6, No. 1, January 1966, pp. 20–22.
(3) Penny, R. K., Ellison, E. G., and Webster, G. A.," Specimen Alignment and Strain Measurement in Axial Creep Tests," *Materials Research and Standards*, ASTM, Vol 6, No. 2, February 1966, pp. 76–84.
(4) Stickley, G. W., and Brownhill, D. J., "Elongation and Yield Strength of Aluminum Alloys as Related to Gage Length and Offset," *Proceedings*, ASTM, Vol 65, 1965, pp. 597–616.
(5) Thomas, J. M., and Carlson, J. F., "Errors in Deformation Measurements for Elevated Temperature Tension Tests," *ASTM Bulletin*, May 1955, pp. 47–51.
(6) Bailey, *Proceedings*, IME 168, 1954, p. 470.
(7) *Journal of Applied Mechanics*, Vol 21, p. 309.
(8) Larson, F. R., and Miller, J., "A Time-Temperature Relationship for Rupture and Creep Stress," *Transactions*, American Society of Mechanical Engineers, Vol 74, p. 765.
(9) Manson, S. S., and Haferd, A. M., "A Linear Time-Temperature Relation for Extrapolation of Creep and Stress-Rupture Data," *NACA Technical Note 2890*, March 1952.
(10) Manson, S. S., and Brown, W. F., "An Investigation of Time-Temperature-Stress Relations for the Correlation and Extrapolation of Stress Rupture Data," *Proceedings*, ASTM, Vol 53, 1953, p. 693.
(11) Jenkins, W. D., et al., "Stress-Rupture Tests at 1350°F on Type 304Stainless Steel," *Materials Research and Standards*, February 1961, pp. 104–108.
(12) Borodin, N. A., and Borshchev, N. I., "Effect of Errors in the Testing Method on the Statistical Spread in Creep and Long-Term Strength Characteristics," *Zavadskaya Laboratoriya*, Vol 37, No. 10, October 1971, pp. 1235–1237, (Translated by Consultants Bureau of Plenum Publishing Corp.).
(13) Phillips, C. W., and Sinnott, M. J., "A Statistical Study of Stress-Rupture Test," *Transactions*, American Society for Metals, Vol 46, 1954, pp. 63–86.
(14) Coutsouradis, D., and Faurschou, D. K.," Cooperative Creep Testing Programme," *AGARD Report No. 581*, March 1971.