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An American National Standard

Standard Test Methods for Elevated Temperature Tension Tests of Metallic Materials[1]

This standard is issued under the fixed designation E 21; 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.

1. Scope

1.1 These test methods cover procedure and equipment for the determination of tensile strength, yield strength, elongation, and reduction of area of metallic materials at elevated temperatures.

1.2 Determination of modulus of elasticity and proportional limit are not included. A method for static determination of modulus of elasticity at elevated temperatures is given in Method E 231.

1.3 Tension tests under conditions of rapid heating or rapid strain rates are not included. Recommended practice for these tests is given in Practice E 151.

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

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

2. Referenced Documents

2.1 *ASTM Standards:*

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 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specification[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 151 Practice for Tension Tests of Metallic Materials at Elevated Temperatures with Rapid Heating and Conventional or Rapid Strain Rates[4]

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[5]

E 231 Method for Static Determination of Young's Modulus of Metals at Low and Elevated Temperatures[6]

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method[3]

3. Terminology

3.1 *Definitions:*

3.1.1 Definitions of terms relating to tension testing which appear in Terminology E 6, shall apply to the terms used in this test method.

3.2 *Definitions of Terms Specific to This Standard:* Definitions of Terms Specific to This Standard:

3.2.1 *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 7.7.

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

3.2.3 *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).

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

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

3.2.6 *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.

3.2.7 *maximum bending strain*—the largest value of bending strain in the reduced section of the specimen. It can be calculated from measurements of strain at three circumferential positions at each of two different longitudinal positions.

4. Significance and Use

4.1 The elevated-temperature tension test gives a useful

[1] These test methods are under the jurisdiction of ASTM Committee E-28 on Mechanical Testing and are 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] Discontinued, see *1983 Annual Book of ASTM Standards*, Vol 03.01.

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

[6] Discontinued, see *1985 Annual Book of ASTM Standards*, Vol 03.01.

estimate of the static load-carrying capacity of metals under short-time, tensile loading. Using established and conventional relationships it can be used to give some indication of probable behavior under other simple states of stress, such as compression, shear, etc. The ductility values give a comparative measure of the capacity of different materials to deform locally without cracking and thus to accommodate a local stress concentration or overstress; however, quantitative relationships between tensile ductility and the effect of stress concentrations at elevated temperature are not universally valid. A similar comparative relationship exists betweentensile ductility and strain-controlled, low-cycle fatigue life under simple states of stress. The results of these tension tests can be considered as only a questionable comparative measure of the strength and ductility for service times of thousands of hours. Therefore, the principal usefulness of the elevated-temperature tension test is to assure that the tested material is similar to reference material when other measures such as chemical composition and microstructure also show the two materials are similar.

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 Precaution should be taken to assure that the load 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 load and at the lowest load 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 strain 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. The scant evidence available at this time[7] indicates that the effect of bending strain on test results is not sufficient, except in special cases, to require the measurement of this quantity on each specimen tested.

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 In general, equipment is not available for determining maximum bending strain at elevated temperatures. The testing apparatus may be qualified by measurements of axiality made at room temperature. When one is making axiality tests 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 Strain measurements at each longitudinal position may be made by the use of four electrical-resistance strain gages equally spaced around the test section[8] of specimens of circular cross section. The two longitudinal positions should be as far apart as is convenient but not closer than one diameter to a fillet.

5.1.2.4 For specimens of rectangular cross section, strain measurements may be made in the center of each of the four sides, or in the case of thin strip, near the outer edges of each of the two broad sides.

5.1.2.5 To eliminate the effect of specimen bias the test should be repeated with the specimen turned 180° and the grips and pull rods retained in their original position.[9] The maximum bending strain and strain at the specimen axis are then calculated from the average of the two readings at the same position relative to the machine.

5.1.2.6 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 shall be equipped with a means of measuring and controlling either the strain rate or the rate of crosshead motion or both to meet the requirements in 9.6.

5.1.4 For high-temperature testing of materials that 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.

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*:

5.3.1 The method of temperature measurement must be sufficiently sensitive and reliable to ensure that the temperature

[7] Subcommittee E28.10 on Effect of Elevated Temperature on Properties requests factual information on the effect of nonaxiality of loading on test results.

[8] Jones, M. H. and Brown, Jr., W. F., "An Axial Loading Creep Machine," ASTM Bulletin, American Society for Testing and Materials, ASTBA, January 1956, pp. 53–60.

[9] Schmieder, A. K., "Measuring the Apparatus Contributions to Bending in Tension Specimens," *Elevated Temperature Testing Problem Areas, ASTM STP 488*, American Society for Testing and Materials, 1971, pp. 15–42.

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 thermocouples of known calibration. 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 specimen 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 Practice E 83, is recommended as a guide for selecting the required sensitivity and accuracy of extensometers. For determination of offset yield strength at 0.1 % or greater, a Class B-2 extensometer may be used. The extensometer should meet the requirements of Practice E 83 and should, in addition, be tested to assure its accuracy when used in conjunction with a furnace at elevated temperature. One such test is to measure at elevated temperature the stress and strain in the elastic range of a metal of known modulus of elasticity. Care should be taken to avoid combinations of stress and temperature which will result in creep of the specimen during the extensometer system evaluation.

NOTE 4—If an extensometer of Class B-2 or better is attached to the reduced section of the specimen, the slope of the stress-strain curve will usually be within 10 % of the modulus of elasticity.

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.[10] 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 When feasible the extensometer should be attached directly to the reduced section of the specimen. When necessary, other arrangements (discussed in 9.6.3) may be used by prior agreement of the parties concerned. For example, special arrangements may be necessary in testing brittle materials where failure is apt to be initiated at an extensometer knife edge.

5.4.4 To attach the extensometer to miniature specimens may be impractical. In this case, separation of the specimen holders or crossheads may be recorded and used to determine strains corresponding to the 0.2 % offset yield strength. The value so obtained is of inferior accuracy and must be clearly marked as “approximate yield strength.” The observed extension should be adjusted by the procedure described in 9.6.3 and 10.1.3.

5.4.5 The extensometer system should include a means of indicating strain rate.

NOTE 5—The strain rate limits listed in 9.6 are difficult to maintain manually by using equipment which has a pacer disk and a follower hand. Equipment that makes timing marks on the edge of the load-strain record requires some trial and error to set the machine controls to give the specified rate during yielding. Such marks are, however, very useful in determining the strain rate after test. Convenient pacers, recently offered by several manufacturers, work on the principle of an indicating tachometer. The machine is manually adjusted to keep the indicator hand of the pacer stationary at a predetermined number.

5.5 *Room-Temperature Control*—Unless the extensometer is known to be insensitive to ambient temperature changes, the range of ambient temperature should not exceed 10°F while the extensometer is attached. The testing machine should not be exposed to perceptibly varying drafts.

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 Specimens and Sample

7.1 The size and shape of the test specimens should be

[10] Tishler, D. N., and Wells, C. H., “An Improved High-Temperature Extensometer,” *Materials Research and Standards*, American Society for Testing and Materials, MTRSA, Vol 6, No. 1, January 1966, pp. 20–22.

based primarily on the requirements necessary to obtain representative samples of the material being investigated.

7.2 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 in. (38 mm) or less in thickness, diameter, or distance between flats.

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

7.3 Specimen configurations described in Test Methods E 8, are generally suitable for tests at elevated temperatures. However, tighter dimensional tolerances are recommended in 7.6. The particular specimen used should be mainly governed by the requirements specified in 7.1. When the dimensions of the material permit, except for sheet and strip, the gage length of the specimens should have a circular cross section. The largest diameter specimen consistent with that described in 7.1 should be used, except that the diameter need not be greater than 0.500 in. (12.7 mm). The ratio of gage length to diameter should be 4, as for the standard specimens described in Test Methods E 8. If different ratios are used, specific attention should be directed to this fact in reporting results.

NOTE 6—Specimen size in itself has little effect on tensile properties provided the material is not subject to appreciable surface corrosion, lack of soundness, 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 is a factor in testing, the results do become 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 7—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.[9,11]

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.[9]

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. This difference should not exceed 0.5 % of the diameter (or width). 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 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 Bureau of Standards. Applicable ASTM methods are listed beside the device.

Load-measuring system	E 4 and E74
Extensometer	E 83
Thermocouples[A]	E 220
Potentiometers	
Micrometers	

[A]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 should be as frequent as is necessary to assure that the errors in all tests do not exceed the permissible variations listed in this test method. The maximum period between calibrations of the testing machine should be one year. Instruments in constant, or nearly constant use should be calibrated more frequently; those used only occasionally should be calibrated before each use.

9. Procedure

9.1 *Measurement of Cross-Sectional Area*—Determine the minimum cross-sectional area of the reduced section of the

[11] Penny, R. K., Ellison, E. G., and Webster, G. A., "Specimen Alignment and Strain Measurement in Axial Creep Tests," *Materials Research and Standards*, American Society for Testing and Materials, MTRSA, Vol 6, No. 2, February 1966, pp. 76–84.

specimen as specified in 5.1.1 of 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 8—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.[12]

9.2.2 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 9.2.3. 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.

9.2.3 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. The strain rate and offset yield calculations are based on this dimension (see 9.6.3, 10.1.2, and 10.3).

NOTE 9—In the yield region, stress is approximately proportional to offset strain to a power which usually lies in the range from zero to 0.20. For specimens of circular cross section the above value of adjusted length of the reduced section was found by calculation to give an error in yield stress of less than ½ % within this range of exponents and for fillet radii ranging from ½ to 1 times the diameter of the reduced section. The method of calculation was similar to that used by Thomas and Carlson.[13]

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 the Preparation of Thermocouple Measuring Junctions, which appears in the *1975 Annual Book of ASTM Standards*, Vol 03.04.

9.4.2 In attaching thermocouples to a specimen, the junction must be kept in intimate contact with the specimen and 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 twisted wires behind the bead). Ceramic insulators should usually be used on the thermocouples in the hot zone. 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 1 in. or more, attach at least two thermocouples to the specimen, one near each end of the length. For lengths of two inches or more add a third thermocouple near the center of the length.

9.4.4 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)	±5°F (3°C)
Above 1800°F (1000°C)	±10°F (6°C)

When testing at temperatures of a few hundred degrees, internal heating due to plastic working may raise the temperature of the specimen above the limits specified. In these cases include the temperature at maximum force and the reason for the overshoot in the report.

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

NOTE 10—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. 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 which 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 20 minutes. Report the time to attain test temperature and the time at temperature before loading.

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

[12] Stickley, G. W., and Brownhill, D. J., "Elongation and Yield Strength of Aluminum Alloys as Related to Gage Length and Offset," *Proceedings*, American Society for Testing and Materials, ASTEA, Vol 65, 1965, pp 597–616.

[13] Thomas, J. M., and Carlson, J. F., "Errors in Deformation Measurements for Elevated Temperature Tension Tests," *ASTM Bulletin*, ASTM, May 1955, pp. 47–51.

transverse direction until the load drops to its minimum value before testing. 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 and Strain Rate*:

9.6.1 The tensile properties of materials tested at elevated temperature are, in general, affected by the rate of deformation. It is therefore important that this rate be controlled and reported.

9.6.1.1 During yield strength determination, maintain the strain rate in the uniform section of the test specimen at 0.005 ± 0.002/min. After yield strength determination increase the rate of crosshead motion to 0.05 ± 0.01 times the adjusted length of the reduced section of the specimen per minute.

9.6.1.2 If it has been established that the crosshead speed remains constant within the tolerance above, the extensometer and strain rate indicator may be used to set a strain rate of 0.05 ± 0.01/min after yield strength determination. To protect it from damage, the sensing element of the extensometer may be removed before maximum load is reached.

NOTE 11—Even with constant crosshead speed, the strain rate in the specimen may still vary. Before maximum load it will be less than the nominal rate due to the elasticity of the machine and grips and the progressive elongation of the specimen. After maximum load it will be greater than the nominal rate due to nonuniform strain during neck down. Available experimental evidence does not justify the added complexity of maintaining a constant strain rate throughout the post-yield stages of a tension test.

9.6.2 When yield strength determination is not required, an extensometer need not be used. A pacing device should be used to maintain the rate of crosshead motion at 0.05 ± 0.01 times the adjusted length of the reduced section of the specimen, per minute.

9.6.3 When yield strength determinations are required, observations of load and extension during loading and through yield are necessary. The following three means of making these observations are acceptable:

9.6.3.1 For specimens of normal size and ductility, attach an extensometer to the reduced section of the specimen.

9.6.3.2 When metals of limited ductility are tested attach the extensometer to the specimen shoulders.

9.6.3.3 For miniature specimens, measure coupling or crosshead separation to determine an approximate yield strength.

9.6.4 When the extensometer is attached to the reduced section of the test specimen, a strain rate indicator should be used to maintain a rate of 0.005 ± 0.002/min during the yielding range. Smaller strain rates are permissible at loads within the elastic range.

NOTE 12—With conventional testing machines, the strain rate often cannot be controlled closely if the material yields in a relatively sudden manner. In such cases the speed control should be preset to the rate which experience shows will result in the specified strain rate at the load corresponding to the yield stress. This will usually be at a strain rate which will result from a rate of crosshead motion of 0.005 times the adjusted length of the reduced section of the specimen, per minute.

9.6.5 When the extensometer is attached to the specimen shoulders, use the adjusted length of the reduced section to calculate the setting of the strain-rate indicator or pacer during yielding. Otherwise the procedure is the same as that described above.

9.6.6 When the stock size requires use of specimens less than 0.25 in. (6.25 mm) in diameter, the approximate 0.2 percent offset yield strength may be determined from a record of coupling or crosshead separation. In order to adjust for the extension which occurs outside the reduced section, two specimens must be tested, one with the standard reduced section and the other, a shortened specimen, with similar grip ends and shoulders but without fillets and reduced section. The latter need only be loaded to the yield load of the former (see 10.1.3).

9.6.7 To allow for the elastic strain in the machine parts, pull rods and grips, set the rate of crosshead motion during yielding at or slightly higher than the upper limit of the recommended range, that is 0.007 times the adjusted length of the reduced section per minute. At strains exceeding that corresponding to the yield strength of the material being tested, apply the method of 9.6.2.

9.7 *Recording Maximum Load*—If an autographic recorder of load and extension is used, continue the recording of load after the sensing element of the extensometer is removed. In any case observe the maximum load and record manually.

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.

9.8.2 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 may be discarded and a retest made.

9.8.3 For measuring reduction of area of specimens of circular cross section, fit the ends of the fractured specimen together carefully and measure the minimum diameter to the nearest 0.001 in. (0.02 mm) at room temperature. If the fracture cross section is not round, make sufficient measurements to establish the cross-sectional area at fracture. 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 may be discarded and a retest made.

10. Calculations

10.1 *Yield Strength*:

10.1.1 Unless otherwise specified determine the yield strength reported at an offset of 0.2 % as described in Test Methods E 8.

NOTE 13—The accurate measurement of proportional limit and offset yield strength of 0.02 % or less is extremely difficult at elevated temperatures. Even though the extensometer has the required accuracy and sensitivity during room-temperature calibration, this is not assurance that the strain measurements during the elevated-temperature tension test will have equal accuracy. High temperature at the attachment points and extensometer rods passing through the furnace packing will probably reduce the accuracy significantly. Therefore, the determination of proportional limit and offset yield strength of 0.02 % or less is not recommended.

10.1.2 If the extensometer must be attached to the specimen shoulders, base the offset extension (inches or millimeters) on the adjusted length of the reduced section, that is, 0.002 times the adjusted length of the reduced section for 0.2 percent offset yield strength and corresponding values for other yield strengths.

10.1.3 If coupling or crosshead separation are recorded adjust the observed extension in the following two steps. First, to compensate for machine elasticity, grip distortion and shoulder strain, reduce values for the standard specimen by the values for the shortened specimen at corresponding loads. Second, treat this adjusted strain datum by the method of 10.1.2. Report only yield strengths with offsets of 0.2 % or more and label these "approximate yield strength.''

10.2 *Tensile Strength*—Calculate the tensile strength by dividing the maximum load, during a test carried to fracture, by the original minimum cross-sectional area of the reduced section of the specimen.

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 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, observed or calculated values shall be rounded off as indicated below, in accordance with the rounding method of Practice E 29 as follows:

Quality Measured	Rounded Unit for Observed or Calculated Value
Tensile or Yield Strength	Nearest 500 psi
Elongation or Reduction of Area	Nearest 0.5 %

11. Report

11.1 The report shall include the following:

11.1.1 Description of material tested, including method of manufacture, type and size of product, and other pertinent processing information, as well as heat treatment, microstructure, and chemical composition.

11.1.2 Specimen dimensions, including cross-sectional dimensions, fillet radius, length of reduced section, adjusted length of reduced section (if used), type of end connection, and whether machined, partially machined, or as cast.

11.1.3 Temperature of test.

11.1.4 Strain rate during yielding and strain rate after yielding.

11.1.5 Yield strength, if required, and drop-of-beam yield point if such a yield point occurs.

11.1.5.1 When one or more values of yield strength are required, the amount of the offsets should be shown with the numerical values.

11.1.5.2 If the extensometer was attached to the specimen shoulders, this fact should be stated in a footnote to the values.

11.1.5.3 If an extensometer was not attached directly to the specimen, the value should be listed as "approximate yield strength (offset = 0.2 %).''

11.1.6 Tensile strength.

11.1.7 Elongation and gage length. If elongation was measured from gage marks not on the reduced section of the specimen this fact should be included in the designation of the quantity, for example" elongation from shoulder measurements'' or "elongation from over-all measurements.'' If elongation was measured from the extensometer record at fracture instead of after fracture, this should be noted.

11.1.8 Reduction of area for specimens with circular cross section.

11.1.9 Time to attain test temperature and time at temperature before testing.

11.1.10 Other special conditions, such as nonstandard atmosphere and heating methods, exceptions to required dimensional accuracy and axiality of loading, amount and duration of temperature overshoot.

11.1.11 Location and description of fracture. The description should include any defects, evidence of corrosion, and type of fracture (such as cup and cone, brittle, shear).

11.1.12 Identification of equipment used including make and capacity of testing machine, make and class of extensometer, make and size of furnace, type of temperature controller, and description of thermocouples including material, wire size, attachment, technique and shielding.

11.1.13 Name of tester and date of test.

12. Precision and Bias

12.1 *Precision*—An interlaboratory test program[14] gave the following values for coefficients of variation for the most commonly measured tensile properties:[15]

Coefficient of Variation, % Tensile Properties at 600°F

	Tensile Strength	Yield Strength offset = 0.2 %	Elongation gage length = 4 diameters	Reduction of Area
CV $\%_r$	1.0	3.0	3.8	4.6
CV $\%_R$	1.4	5.1	8.2	4.9

CV $\%_r$ = repeatability coefficent of variation in percent within a laboratory.
CV $\%_R$ = repeatability coefficient of variation in percent between laboratories.

[14] Supporting data are available from ASTM Headquarters. Request RR:E28-1015.

[15] For further information, see Practice E 177 and Practice E 691.

Coefficient of Variation, % Tensile Properties at 1100°F

	Tensile Strength	Yield Strength offset = 0.2 %	Elongation gage length = 4 diameters	Reduction of Area
CV $\%_r$	1.7	4.0	3.1	2.2
CV $\%_R$	4.4	4.4	11.1	4.5

CV $\%_r$ = repeatability coefficent of variation in percent within a laboratory.
CV $\%_R$ = repeatability coefficient of variation in percent between laboratories.

12.1.1 The values shown are the averages from tests on four frequently tested metals at two test temperatures, selected to include most of the normal range for each property listed above. When these materials are compared, a large difference in coefficient of variation is found. Therefore, the values above should not be used to judge whether the difference between duplicate tests of a specific material islarger than expected. The values are provided to allow potential users of this test method to assess, in general terms, its usefulness for a proposed application.

12.2 *Bias*—The procedures in Test Methods E 21 for measuring tensile properties have no bias because these properties can only be defined in terms of a test method.