Designation: E 21 – 92 (Reapproved 1998)$^{\epsilon 1}$

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.

ϵ^1 Note—Sections 9.4.4 and 9.4.6 were editorially updated in January 2002.

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

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[1] These test methods are under the jurisdiction of ASTM Committee E28 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.

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 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

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[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.

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 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 reused 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.

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[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.

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 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.

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[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.