Designation: E 292 – 01

Standard Test Methods for Conducting Time-for-Rupture Notch Tension Tests of Materials[1]

This standard is issued under the fixed designation E 292; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 These test methods cover the determination of the time for rupture of notched specimens under conditions of constant load and temperature. These test methods also includes the essential requirements for testing equipment.

1.2 The values stated in inch-pound units are to be regarded as the standard. The units in parentheses are for information only.

1.3 *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:*

A 453/A453M Specification for High-Temperature Bolting Materials, with Expansion Coefficients Comparable to Austenitic Steels[2]

E 4 Practices for Force Verification of Testing Machines[3]

E 6 Terminology Relating to Methods of Mechanical Testing[3]

E 8 Test Methods for Tension Testing of Metallic Materials[3]

E 74 Practice of Calibration of Force-Measuring Instruments for Verifying the Load Indication of Testing Machines[3]

E 139 Practice for Conducting Creep, Creep-Rupture, and Stress-Rupture Tests of Metallic Materials[3]

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

E 633 Guide for Use of Thermocouples in Creep and Stress Rupture Testing to 1000°C (1800°F) in Air[3]

E 1012 Practice for Verification of Specimen Alignment Under Tensile Loading[3]

2.2 *Military Standard:*

MIL-STD-120 Gage Inspection[5]

3. Terminology

3.1 *Definitions*—The definitions of terms relating to creep testing, which appear in Section E of Terminology E 6 shall apply to the terms used in these test methods. 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 reduced section of the specimen.

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

3.2.4 *length of the reduced section*—the distance between tangent points of the fillets that bound the reduced section.

3.2.5 The adjusted length of the reduced section is greater than the length of the reduced section by an amount calculated to compensate for the strain in the fillets adjacent to the reduced section.

3.2.6 *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.

3.2.7 *reduced section of the specimen*—the central portion of the length having a cross section smaller than that of the ends that are gripped. The reduced section is uniform within tolerances prescribed in Test Methods E 8.

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[1] These test methods are under the jurisdiction of ASTM Committee E28 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 01.01.

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

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

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

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

4. Significance and Use

4.1 Rupture life of notched specimens is an indication of the ability of a material to deform locally without cracking under multi-axial stress conditions, thereby redistributing stresses around a stress concentrator.

4.2 The notch test is used principally as a qualitative tool in comparing the suitability of materials for designs that will contain deliberate or accidental stress concentrators.

5. Apparatus

5.1 *Testing Machine*:

5.1.1 The testing machine shall ensure the application of the load to an accuracy of 1 % over the working range.

5.1.2 The rupture strength of notched or smooth specimens may be reduced by bending stresses produced by eccentricity of loading (that is, lack of coincidence between the loading axis and the longitudinal specimen axis). The magnitude of the effect of a given amount of eccentricity will increase with decreasing ductility of the material and, other things being equal, will be larger for notch than for smooth specimens. Eccentricity of loading can arise from a number of sources associated with misalignments between mating components of the loading train including the specimen. The eccentricity will vary depending on how the components of the loading train are assembled with respect to each other and with respect to the attachments to the testing machine. Thus, the bending stress at a given load can vary from test to test, and this variation may result in a substantial contribution to the scatter in rupture strength **(1, 2)**.[6]

5.1.3 Zero eccentricity cannot be consistently achieved. However, acceptably low values may be consistently achieved by proper design, machining, and assembly of all components of the loading train including the specimen. Devices that will isolate the loading train from misalignments associated with the testing machine may also be used. For cylindrical specimens, precision-machined loading train components employing either buttonhead, pin, or threaded grips connected to the testing machine through precision-machined ball seat loading yokes have been shown to provide very low bending stresses when used with commercial creep testing machines **(3)**. However, it should be emphasized that threaded connections may deteriorate when used at sufficiently high temperatures and lose their original capability for providing satisfactory alignment.

5.1.4 Whatever method of gripping is employed, the testing machine and loading train components when new should be capable of loading a verification specimen at room temperature as described in 7.2 so that the maximum bending strain is 10 % or less at the lowest anticipated applied force in the creep-rupture test. It is recognized that this measurement will not necessarily represent the performance in the elevated-temperature rupture test, but is designed to provide a practical means of evaluating a given testing machine and its associated loading train components. Generally, the eccentricity of loading at elevated temperatures will be reduced by the higher compliance, lower modulus of various mating parts as compared with the verification test at room temperature. However, it should be recognized that depending on the test conditions, the fits between mating parts may deteriorate with time and that furnace seals if not properly installed could cause lateral forces to be applied to the loading rods. In either case, misalignments may be increased relative to the values measured at room temperature for new equipment. Axiality requirements and verifications may be omitted when testing performed is for acceptance of material to minimum strength requirements. As discussed in 5.1.2, excessive bending would result in reduced strength or conservative results. In this light, should acceptance tests pass minimum requirements, there would be little benefit to improving axiality of loading. However, if excessive bending resulted in high rejection rates, economics would probably favor improving axiality.

5.1.4.1 Test Method E 1012 or equivalent shall be used for the measurement and calculation of bending strain for cylindrical or flat specimens.

5.1.5 This requirement is intended to limit the maximum contribution of the testing apparatus to the bending that 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.

5.1.6 The testing machine should incorporate means of taking up the extension of the specimen so that the applied force 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 5.1.4. The take-up mechanism should avoid introducing shock or torque forces to the specimen, and overloading due to friction, or inertia in the loading system.

5.1.7 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 when a specimen fractures.

5.1.8 For high-temperature testing of materials that are readily attacked by their environment (such as oxidation of metal in air), the sample 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 and maintain accurate specimen applied forces must be made. For instance, compensation must be made for differences in pressures inside and outside of the capsule and for any applied force variation due to sealing ring friction, bellows, or other load train 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 5.3.1 without manual adjustment more frequent than once in each 24-h period after application of force.

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[6] The numbers in boldface type refer to the list of references at the end of this standard.

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 1—The medium 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.

5.3 *Temperature Control*:

5.3.1 Indicated specimen temperature variations along the reduced section and notch(es) on the specimen should not exceed the following limits initially and for the duration of the test:

Up to and including	1800 ± 3°F (980 ± 1.7°C)
Above	1800 ± 5°F (980 ± 2.8°C)

5.3.1.1 Guide E 633 or equivalent shall be used for the thermocouple preparation and use.

5.3.2 The temperature should be measured and recorded at least once each working day. Manual temperature readings may be omitted on non-working days provided the period between reading does not exceed 48 h. Automatic recording capable of assuring the above temperature limits at the notch(es) may be substituted for manual readings provided the record is read on the next working day.

5.3.3 For a notch-only specimen, a minimum of one thermocouple at or near the notch (either notch for a flat specimen) is required. For a combination of smooth and notched specimens, in addition to the one thermocouple required at or near the notch, one or more thermocouples will be required in the unnotched gage section. If the unnotched gage section is 1 in. (25.4 mm) or less, a minimum of one additional thermocouple placed at the center of the gage is required. For unnotched gage sections greater than 1 in. (25.4 mm), at least two additional thermocouples at or near the fillets are required. If thermal gradients are suspected to be greater than the limits given in 5.3.1, additional thermocouples should be added. For specimens with unnotched gage sections of 1 in. or less, position the additional thermocouples at or near the fillets. For specimens with unnotched gage sections greater than 1 in., position the additional thermocouples uniformly along the gage section.

5.3.4 The terms "indicated nominal temperature" or "indicated temperature" mean the temperature that is indicated on the specimen by the temperature-measuring device using good pyrometric practice.

5.3.5 The heating characteristics of the furnace and the temperature control system should be studied to determine the power input, voltage fluctuation, temperature set point, proportioning control adjustment, reset adjustment, and control thermocouple placement necessary to limit transient temperature overshoot and overheating due to set point error. Overheating prior to attaining the limits specified in 5.3.1 should not exceed 25°F (14°C) above the indicated nominal test temperature, the duration of such overheating not to exceed 20 min.

5.3.6 In testing materials that are subjected to changes in mechanical properties due to any overheating, and all alloys where the test temperature is at or above the temperature of final heat treatment, overheating should not exceed the limits in 5.3.1.

6. Test Specimens

6.1 The size and shape of test specimens should be based primarily on the requirements necessary to obtain representative samples of the material being investigated. If at all possible, the specimens should be taken from material in the form and condition in which it will be used.

6.2 Specimen type, size, and shape have a large effect on rupture properties of notch specimens **(4, 5, 6, 7)**. In a notched specimen test, the material being tested most severely is the small volume at the base of the notch.

6.3 Selection of the exact specimen geometry and the machining practice used to achieve this geometry and the methods used to measure it should be agreed upon by all parties concerned because of the influence of these factors on rupture life.

NOTE 2—The notch rupture strength is not only a function of the theoretical stress concentration, K_t, but also of the absolute size of the specimen, even though the various specimens used are geometrically similar. Therefore, a comparison of material or different conditions of the same material on the basis of their notch rupture strength can only be made from test results on the same size specimen.

6.4 Numerous different specimen geometries have been used; some cylindrical specimens are suggested in Fig. 1. A similar specimen is described in Specification A 453/A 453M. Separate plain and notched specimens may be used instead of the combination specimen described in Fig. 1. Suggested flat specimens are shown in Fig. 2. Notch preparation methods should be chosen to minimize the surface effect and residual stresses.

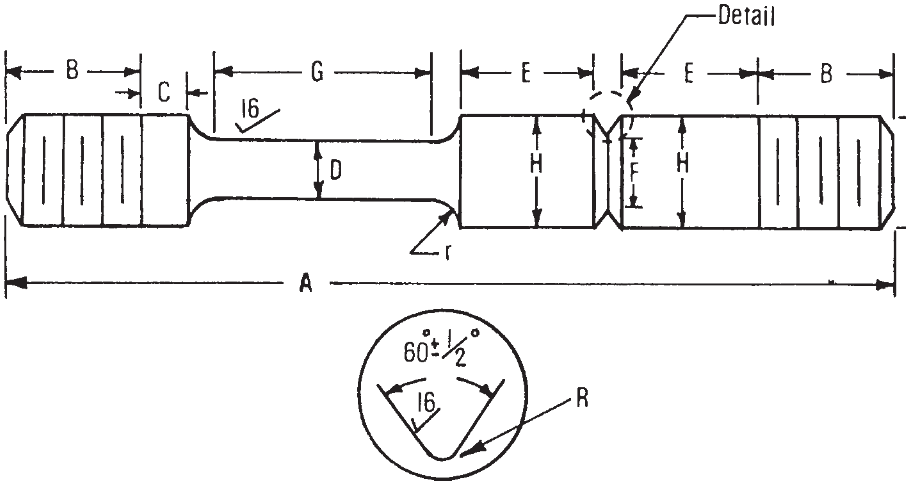
NOTE 3—Dimensions of specimens are given in inch-pound units, and metric units are not always exact arithmetic equivalents (except for tolerances which are reasonable equivalents) but have been adjusted to provide practical equivalents for critical dimensions while retaining geometric proportionality.

6.5 Various methods of attachment of the specimen to the loading train may be used. Threaded attachments are shown in Fig. 1 for cylindrical specimens, but buttonhead, tapered, or pin attached may be used. The flat specimen types shown in Fig. 2 may be attached through loading yokes and pins or by wedge grips. If sufficient test material is available, the specimen head length may be increased to permit attachment to the loading train at a point outside the furnace. Removing the attachment outside the furnace has the advantage that these components are not subjected to the test temperature and should therefore have longer useful lives than similar attachments used inside the furnace.

6.6 Whatever method of gripping is used, care should be taken to minimize the eccentricity of loading, and in all cases the requirements of 5.1.4 for permissible percent bending shall be met.

7. Verification and Standardization

7.1 The following devices should be verified against standards traced to the National Institute of Standards and Technology. Applicable ASTM standards are listed beside the device.



	Specimen 1		Specimen 2		Specimen 3		Specimen 4		Specimen 5		Specimen 6	
	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm
D-Diameter of gage	0.125± 0.001	3.18± 0.012	0.150± 0.001	3.81± 0.012	0.160± 0.001	4.06± 0.012	0.178± 0.001	4.52± 0.012	0.252± 0.001	6.4± 0.025	0.357± 0.001	9.07± 0.025
G-Gage length	0.50± 0.05	12.7± 1.3	0.60± 0.05	15.2± 1.3	0.65± 0.05	16.5± 1.3	0.75± 0.05	19.05± 1.3	1.0± 0.05	24.5± 1.3	1.5± 0.05	38.1± 1.3
R-Radius of notch	0.0035± 0.0005	0.09± 0.01	0.004± 0.0005	0.10± 0.01	0.0045± 0.0005	0.11± 0.01	0.005± 0.0005	0.13± 0.01	0.0075± 0.0005	0.19± 0.01	0.010± 0.0005	0.25± 0.01
E-Shoulder length (approx)	¼	6.4	5⁄16	8.0	5⁄16	8.0	⅜	9.5	½	12.7	¾	19.0
H-Shoulder diameter (Major)	0.177± 0.003	4.5± 0.08	0.212± 0.003	5.4± 0.08	0.226± 0.003	5.7± 0.08	0.250± 0.003	6.4± 0.08	0.375± 0.003	9.5± 0.08	0.500± 0.003	12.7± 0.08
r-Radius of fillet	3⁄32	2.4	3⁄32	2.4	3⁄32	2.4	⅛	3.2	3⁄16	4.7	¼	6.4
K_t-Stress concentration factor	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9

NOTE 1—Surfaces marked^{16}, finish to 16 µin., rms or better.

NOTE 2—The difference between dimensions *F* and *D* shall not exceed 0.001 in. (0.025 mm).

NOTE 3—Taper the gage length *G* to the center so that the diameter *D* at the end of the gage length exceeds the diameter at the center of the gage length by no less than 0.0005 in. (0.01 mm) nor more than 0.0015 in. (0.04 mm).

NOTE 4—All sections shall be concentric about the specimen axis within 0.001 in. (0.025 mm).

NOTE 5—Threads *T* may be any convenient size, but root diameter must be greater than *F*. Some brittle materials may require root diameter equal to or greater than *H*.

NOTE 6—Dimensions *A* and *B* are not specified, but *B* shall be equal to or greater than *T*.

NOTE 7—Shoulder length *C* shall be ⅛ in. (3.2 mm) min.

NOTE 8—K_t, stress concentration factor (see Ref (**9**)).

FIG. 1 Standard Cylindrical Specimens

Loading-measuring system	Practices E 4 and E 74
Thermocouples	Method E 220. Melting point methods are also recommended for thermocouple calibration.
Potentiometers	Method E 220 and STP 470 A[7]
Micrometers	MIL-STD-120 Gage Inspection[5]

7.2 Verification of the axiality of loading in terms of conformance to the percent bending requirement of 5.1.4 is considered as part of calibration and standardization procedure. Use a specimen as shown in Fig. 3. Apply strain gages to the specimen in a configuration outlined in Practice E 1012.

7.3 Verifications of the force-measuring system and temperature-measuring and control system should be made as frequently as necessary to assure that the errors for each test are less than the permissible variations listed in this recommended practice. The maximum period between these types of calibrations should be one year, or after each test when the tests last longer than one year. Verification of the axiality of loading should be repeated whenever loading rods are replaced and at some regular intervals, which are best determined by experience and will depend on the severity of the testing conditions.

8. Procedure

8.1 *Measurement of Cylindrical Specimens*:

8.1.1 Determine the minimum diameter at the root of the notch and the diameter at 90 deg to the minimum to the nearest 0.0005 in. (0.01 mm). Use the average of these two diameters to calculate the area.

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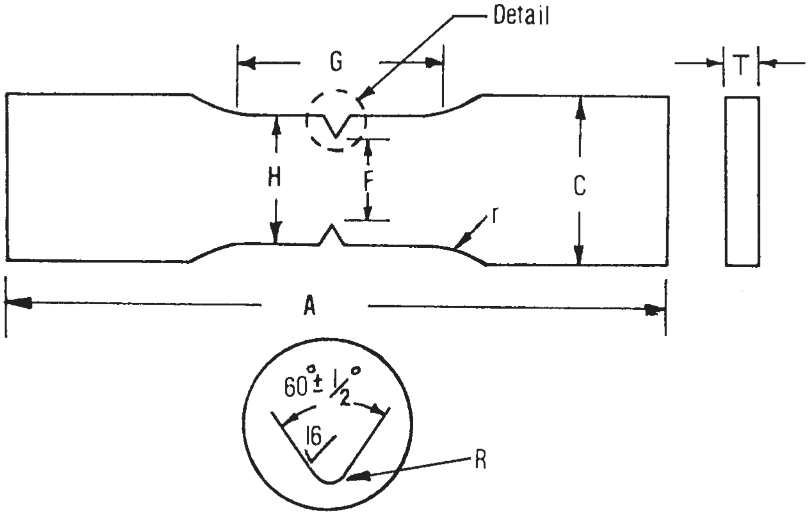
[7] *Manual on the Use of Thermocouples in Temperature Measurement, ASTM STP 470 A,* ASTM, 1971.



	Specimen 1		Specimen 2		Specimen 3		Specimen 4		Specimen 5		Specimen 6	
	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm
F-Notch width	0.125± 0.001	3.18± 0.025	0.150± 0.001	3.81± 0.025	0.160± 0.001	4.06± 0.025	0.175± 0.001	4.45± 0.025	0.250± 0.001	6.35± 0.025	0.350± 0.001	8.89± 0.025
H-Major width	0.225± 0.003	5.71± 0.08	0.230± 0.003	5.84± 0.08	0.230± 0.003	5.84± 0.08	0.250± 0.003	6.35± 0.08	0.375± 0.003	9.53± 0.08	0.500± 0.003	12.70± 0.08
R-Radius of notch	0.005± 0.0005	0.13± 0.01	0.0055± 0.0005	0.14± 0.01	0.0055± 0.0005	0.14± 0.01	0.006± 0.0005	0.15± 0.01	0.009± 0.0005	0.23± 0.01	0.012± 0.0005	0.30± 0.01
G-Gage length (approx)	¾	19.0	¾	19.0	¾	19.0	¾	19.0	1	25.4	1½	38.1
C-Shoulder width (min)	⅜	9.53	⅜	9.53	⅜	9.53	⅜	9.53	9⁄16	14.29	¾	19.0
K_t-Stress concentration factor	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5

NOTE 1—Surfaces marked^{16}, finish to 16 μin. rms or better.

NOTE 2—Dimension *A* is not specified, but shall be of such length to accommodate gripping ends.

NOTE 3—Dimension *T*, is thickness of material, but greater than 5 and less than 10 times the notch root radius.

NOTE 4—Radius *r* shall be ½ + 1⁄32 -0 in. (12.7 + 0.8 mm).

NOTE 5—K_t, stress concentration factor (see Ref **(9)**).

FIG. 2 Standard Flat Specimens

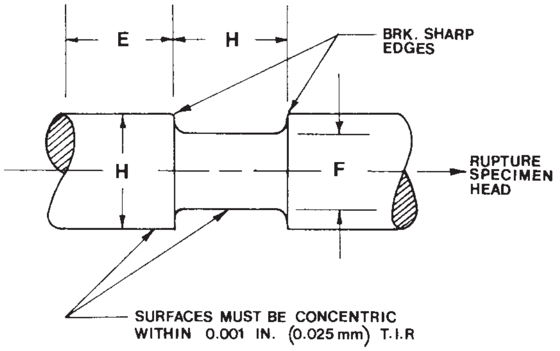


FIG. 3 Cylindrical Verification Specimen Test Section

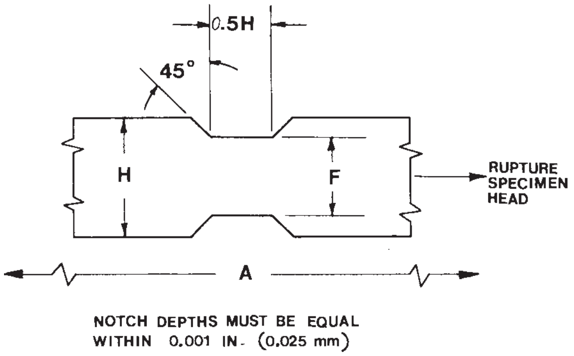


FIG. 4 Test Section of Flat Verification Specimen

8.1.2 Measure the major diameters in a corresponding manner.

8.1.3 Measure the distance between punched or scribed marks on the shoulders of the gage section or, if ductility permits, between the punch or scribe marks spaced four diameters apart on the unnotched reduced section, but with a longer gage length permitted by mutual agreement.

8.1.4 Scribe an axial line on major-diameter sections to assist fitting of fractured ends after testing.

8.1.5 Measure the root radius of the notch to the nearest 0.0005 in. (0.01 mm). Useful information can be obtained by tracing the notch profile on an optical comparator.

8.2 *Measurement of Flat Specimens*:

8.2.1 Measure minimum width at the root of the notch to within 0.0005 in. (0.01 mm).

8.2.2 Measure the major width on each side of the notch in a corresponding manner.

8.2.3 Measure the thickness at each edge and at the middle of the width. Use the average thickness and width to calculate area.

8.2.4 Measure the root radii of the notch to the nearest 0.0005 in. (0.01 mm). Useful information can be obtained by tracing the notch profile on an optical comparator.

8.3 *Cleaning Specimen*—Carefully wash the notch and the reduced section and those parts of the specimen which contact the grips in clean solvent that will not affect the metal being tested. Acetone with an alcohol rinse is commonly used for those metals which are not affected thereby.

8.4 *Temperature-Measuring Apparatus* **(8)**—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 5.3.1.

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

NOTE 4—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-conducting along thermocouple wire, etc.

8.4.2 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 reused without clipping back to remove wire exposed to the hot zone and remaking. Any reuse of base-metal thermocouples after relatively low-temperature use without this precaution should be accompanied by recalibration data demonstrating that the calibration was not unduly affected by the conditions of exposure.

8.4.3 Noble-metal thermocouples are also subject to error 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.

8.4.4 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 reading 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.

8.4.5 Temperature-measuring, controlling, and recording instruments should be calibrated periodically against a secondary standard, such as precision potentiometer. A record of this verification/calibration should be maintained. Appropriate calibration/verification periods are defined in Practice E 139 (8.2). Lead wire error should be checked with the lead wires in place as they normally are used.

8.5 *Thermocouple Attachment*:

8.5.1 In attaching thermocouples to specimens it is important that the junction be kept in intimate contact with the specimen and shielded from radiation. The locations of the required thermocouples are given in 5.3.3.

8.5.2 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 5.3.1. The bead should be as small as practical, 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 assure that the electrical insulating properties are maintained at higher temperatures.

8.6 *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 pull rods are displaced or their movement restricted.

8.7 *Loading Procedure*:

8.7.1 A small fraction of the initial test force (not more than 10 %) may be applied before and during heating of the specimen. This usually improves the axiality of force application by reducing the displacement of the specimen and loading rods due to lateral forces from furnace packing and thermocouple wire (see 8.6).

8.7.2 Apply the test force in a manner that avoids shock, overloading due to inertia, or application of torque. The testing force may be applied incrementally, but the application time should be minimized.

8.7.3 Provide suitable means for measuring the elapsed time between complete application of the test force and the time at which fracture of the specimen occurs, to within 1 % of the elapsed time.

8.8 *Measurement of Specimens After Test*—In order to obtain the information required in Section 9, it is necessary to determine the final notch area of the specimen after rupture. For cylindrical specimens this can sometimes be done by fitting the broken halves together in a suitable fixture and measuring the minimum and maximum diameters at the notch section with pointed micrometers. For very small diameter specimens, or where the irregularities of the fracture surface preclude matching of the broken halves, a measuring microscope should be used to determine these values. For flat specimens, the major reduction in dimension will be in the thickness direction, and the final width and thickness at the notch section can best be obtained using a measuring microscope.

8.8.1 For measuring elongation, fit the ends of the fractured specimen together carefully and measure the distance between gage marks to the nearest 0.01 in. (0.2 mm) at room temperature. If any part of the fracture surface extends beyond the center 50 % of the reduced section, 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. Calculation

9.1 Calculate the notch rupture strength as follows:

$$\text{Notch rupture strength} = P/A_O \tag{1}$$

where:

P = the load applied to the specimen, and

A_O = the initial area at the notch cross section.

9.2 Calculate the percent reduction in area at the notch cross section and the true strain at this location as follows:

$$\text{Percent reduction in area} = \frac{A_O - A_f}{A_O} \times 100 \tag{2}$$

$$\text{True fraction strain} = \epsilon_N = \ln A_O/A_f \tag{3}$$

where A_f is the final area at the notch section, determined as follows:

$$\text{For cylindrical specimens, } A_f = \frac{\pi ab}{4} \tag{4}$$

$$\text{For flat specimens, } A_f = W_f T_f \tag{5}$$

where a and b are the minimum and maximum final diameters of the cylindrical specimens and W_f and T_f the final width and thickness of flat specimens, all determined as specified in 8.8.

9.3 Calculate the elongation in unnotched gage length as described in Practice E 139.

9.4 Calculate the K_t factor using Ref **(9)** and *R, F, D,* or *H* (Fig. 1 and Fig. 2).

9.5 *Incidental Information*—The notch rupture strength ratio at a given rupture time and the notch rupture time ratio at a given rupture strength are useful when comparing the notch sensitivity of various materials or investigating the effects of such factors as specimen size, composition, heat treatment, fabrication history, etc. **(10, 11)**. When the notch rupture strength ratio and the reduction in area or the true strain are plotted as a function of rupture time, any instabilities within the testing time range may be revealed by decreases in these quantities with increasing rupture time. The required ratios are defined as follows:

$$\text{Notch rupture strength ratio} = \frac{\text{rupture strength of notched specimen}}{\text{rupture strength of smooth specimen}} \tag{6}$$

where both strength values are obtained for the same testing conditions and correspond to the same rupture time.

$$\text{Notch rupture time ratio} = \frac{\text{rupture time of notched specimen}}{\text{rupture time of smooth specimen}} \tag{7}$$

where the rupture times correspond to the same applied stress and the same testing conditions. These ratios may be calculated from plots of the primary data of smooth and notch rupture strength as a function of rupture time. It is desirable that the smooth specimen data be derived from tests on specimens having test sections of a diameter close to the notch diameter of the notched specimens and, of course, should represent exactly the same material conditions.

10. Report

10.1 The following information concerning the specimens, testing conditions, and the results of the test shall be reported:

10.1.1 *Specimen* (cylindrical):

10.1.1.1 Type—combined notched and smooth or notched only,

10.1.1.2 Initial shoulder diameter, *H*,

10.1.1.3 Initial notch diameter, *F*,

10.1.1.4 Final minimum notch diameter, *a*,

10.1.1.5 Final maximum notch diameter, *b*,

10.1.1.6 Initial notch radius, *R*, and

10.1.1.7 Initial gage diameter for combined specimen, *D*.

10.1.2 *Specimen* (flat):

10.1.2.1 Initial gage width, *H*,

10.1.2.2 Initial notch width, *W*,

10.1.2.3 Final notch width, W_f,

10.1.2.4 Initial thickness at notch section, *T*,

10.1.2.5 Final thickness at notch section, T_f, and

10.1.2.6 Notch radius, *R*.

10.1.3 *Testing Conditions*:

10.1.3.1 Load applied to specimen, *P* (kg),

10.1.3.2 Temperature of test, °F (°C), and

10.1.3.3 Description of any atmosphere other than laboratory air

10.1.4 *Results*:

10.1.4.1 Time to failure, h (hours to nearest 0.1 h for test durations of 100 h or less, to nearest 1.0 h for test durations over 100 h),

10.1.4.2 Time to test discontinuance if no failure, h (hours to nearest 0.1 h for test durations of 100 h or less, to nearest 1.0 h for test durations over 100 h),

10.1.4.3 Notch rupture strength (Section 9),

10.1.4.4 Percent reduction in area (Section 9), and

10.1.4.5 True fracture strain (Section 9).

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

10.2.1 *Material Being Tested*:

10.2.1.1 Type of alloy, producer, and heat number,

10.2.1.2 Chemical composition (specify ladle or check analysis),

10.2.1.3 Type of melting used to produce the alloy,

10.2.1.4 Size of heat,

10.2.1.5 Deoxidation practices,

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

10.2.1.7 Fabrication history of material,

10.2.1.8 Heat treatment,

10.2.1.9 Grain size,

10.2.1.10 Hardness,

10.2.1.11 Any special machining techniques used to produce the notch geometry, 10.2.1.12 Short-time tensile properties at room temperature and at the rupture test temperature,

10.2.1.13 Pretest conditioning of the specimen, and

10.2.1.14 Theoretical stress concentration factor, K_t.

10.2.2 *Equipment Description*:

10.2.2.1 Make, model, and capacity of testing machine,

10.2.2.2 Make and model of temperature-measuring instrument,

10.2.2.3 Make and model of temperature controller,

10.2.2.4 Number of thermocouples, thermocouple material, wire size, attachment technique, and shielding, and

10.2.2.5 Identification and calibration of thermocouple wire and identification number and calibration record of potentiometer.

10.2.3 *Information on Machine*:

10.2.3.1 Identifying number,

10.2.3.2 Lever,

10.2.3.3 Lever ratio,

10.2.3.4 Calibration data for load system,

10.2.3.5 Lever friction, percent, as a function of load, and other friction, if any, with sources,

10.2.3.6 Similar applicable data for other types of loading systems,

10.2.3.7 Loading history (time and load increments),

10.2.3.8 Report of axiality test, and

10.2.3.9 Type of grip (threaded, pinned, shouldered, etc.) and whether the specimen was machined or as-cast.

10.2.4 *Temperature*:

10.2.4.1 Variation along reduced section at a given time,

10.2.4.2 Maximum swing due to on-off or high-low cycling,

10.2.4.3 Long-time drift,

10.2.4.4 Change in thermocouple calibration from before test to after test,

10.2.4.5 Frequency of reading,

10.2.4.6 Description of equipment used to measure temperature,

10.2.4.7 Time at indicated nominal test temperature prior to load application and time and amount of overshoot, if any,

10.2.4.8 Frequency and amplitude of temperature cycling before loading,

10.2.4.9 Room temperature at time of loading,

10.2.4.10 Date and time of day of each observation,

10.2.4.11 Date and time of day, and magnitude of each furnace control adjustment made after load is applied to the specimen, and

10.2.4.12 Record of room temperature in the laboratory.

10.2.5 *Other*:

10.2.5.1 The specimen itself or a record of its disposition, and

10.2.5.2 Signature of responsible technician or operator.

11. Precision and Bias

11.1 There are few published experimental data on the variation of notch rupture life for duplicate tests. One paper **(3)** reports tests made with extraordinary care to reduce bending using a single machine. The results are probably representative of the minimum scatter to be expected. Five tests on embrittled Cr-Mo-V steel tested at 60 ksi (415 MPa) and 1000°F (538°C) failed in the range from 83 to 93 h, or time ratio (longest/shortest) of 1.12. Another investigation **(5)** of a similar material in a notch-strengthened condition under more typical conditions of bending gave a range from 1800 to 10 000 h for four specimens 0.25 in. (6.3 mm) in diameter or a time ratio of 5.5 and a range from 830 to 4500 h or a time ratio of 5.4, for four 1-in. (25.4 mm) diameter specimens when tested at 45 ksi (310 MPa) and 1000°F. There are no standard materials or specimen banks for notched rupture specimens, so no estimate of bias is available at this time. However, round-robin testing programs are now under way and some information on reproducibility will be available soon.

11.2 Another approach to an estimate of precision is to calculate the effect of the permitted tolerance in force, temperature, and diameter measurement on the time to failure. The formulas for this purpose were obtained by the usual method **(12)** which involves taking the partial derivative of the time with respect to the other three variables in turn and multiplying by the estimated error, which in this case was taken as the permitted tolerance. The effects of each of the separate quantities are combined by taking the square root of the sum of their square.

11.3 The proportional error in stress due to an error in root diameter measurement (of a circular cross-section specimen) and the error in applied force is found to be:

$$\frac{\Delta\sigma}{\sigma} = \sqrt{\left(\frac{-2\,\Delta D}{D}\right)^2 + \left(\frac{\Delta P}{P}\right)^2} \tag{8}$$

where:
σ = stress,
D = root diameter,
P = applied force, and
Δ = error in the following quantity.

11.4 The effect on time to rupture of the error in stress and of the error in temperature is similarly found to be:

$$\frac{\Delta t}{t} = \sqrt{\left(\frac{1}{n}\,\frac{\Delta\sigma}{\sigma}\right)^2 + \left(\frac{\Delta T}{T^2\,m}\,t^2\right)} \tag{9}$$

where:
t = time to rupture,
T = absolute temperature,
n = slope of a plot of log stress (ordinate) versus log time (abscissa) for isothermal tests, and
m = slope of a plot of reciprocal of absolute test temperature (ordinate) versus log time (abscissa) for tests at the same stress.

11.5 The references cited did not give results for different stresses and temperatures for the material tested. In order to compare the results from these formulas to the experimental values given above, unpublished data on a different heat of 1Cr-1Mo-1/4V in notch strengthening condition is used. The slope m was measured from tests at 1000°F (538°C) and 35, 40, 45, and 50 ksi (240, 275, 310, and 345 MPa). The values of permissible error are taken from this practice. The data and results are:

$$D = 0.250\text{ in.} \quad \Delta D = 0.001\text{ in.} \quad \Delta P/P = 0.01\ \Delta\,\sigma/\sigma = 0.013 \tag{10}$$

$$n = 0.15 \quad \Delta T = 3°\text{F or }°\text{R} \quad m = 42 \times 10^{-6}$$

$$\Delta T = 1460°\text{R} \quad \Delta t/t = 0.093$$

Therefore, the highest value of time to rupture for a group of tests would be expected to be 1.093 times the average value and the lowest 0.907 times the average value and their ratio equal to 1.20. This is in good agreement with the corresponding value of 1.12 for the five tests with minimum bending but is far from the experimental scatter for the tests under more typical conditions. This discrepancy is at least partially due to factors that could not be included in the analysis because of insufficient experimental data. These are

11.5.1 The effect of bending which is known **(1)** to shorten life at least for materials of low ductility.

11.5.2 The effect of notch machining methods.

11.5.3 The Z-shaped stress-time plot **(13)** which results in an increase in life with decreasing stress in narrow stress range for some materials and has the appearance of scatter.

11.6 The generally accepted opinion that the scatter in rupture testing results (that is, rupture life) is greater for notched specimens than for unnotched specimens may be due to the smaller effect of these three variables on the unnotched specimens.

12. Keywords

12.1 axiality; bending strain; bending stress; elongation; final notch cross-sectional area; gage length; k_t factor; loading; major diameter; minor diameter; notch cross-sectional area; notch root radius; notch rupture strength; stress; stress-rupture; temperature; thermocouple

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