



Standard Test Methods of Tension Testing Wrought and Cast Aluminum- and Magnesium-Alloy Products¹

This standard is issued under the fixed designation B 557; 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 the tension testing of wrought and cast aluminum- and magnesium-alloy products, excepting aluminum foil², and are derived from Test Methods E 8, which cover the tension testing of all metallic materials.

1.2 *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.*

NOTE 1—Exceptions to the provisions of these test methods may need to be made in individual specifications or test methods for a particular material.

NOTE 2—A complete metric companion to Test Methods B 557 has been developed—Test Methods B 557M; therefore, no metric equivalents are presented in these test methods.

2. Referenced Documents

2.1 The following documents of the issue in effect on the date of material purchase form a part of these test methods to the extent referenced herein:

2.2 ASTM Standards:

E 4 Practices for Force Verification of Testing Machines³

E 6 Terminology Relating to Methods of Mechanical Testing³

E 8 Test Methods for Tension Testing of Metallic Materials³

E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications⁴

E 83 Practice for Verification and Classification of Extensometer System³

E 345 Test Methods of Tension Testing of Metallic Foil³

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method⁴

¹ These test methods are under the jurisdiction of ASTM Committee B07 on Light Metals and Alloys and are the direct responsibility of Subcommittee B07.05 on Testing.

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² For test methods of tension testing of aluminum foil, see Test Methods E 345.

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

⁴ *Annual Book of ASTM Standards*, Vol 14.02.

E 1012 Practice for Verification of Specimen Alignment Under Tensile Loading³

3. Terminology

3.1 The definitions of terms relating to tension testing appearing in Terminology E 6 shall be considered as applying to the terms used in these test methods.

4. Significance and Use

4.1 Tension tests provide information on the strength and ductility of materials under uniaxial tensile stresses. This information may be useful in comparisons of materials, alloy development, quality control, and design under certain circumstances.

4.2 The results of tension tests of specimens machined to standardized dimensions from selected portions of a part or material may not totally represent the strength and ductility properties of the entire end product or its in-service behavior in different environments.

4.3 These test methods are considered satisfactory for acceptance testing of commercial shipments and have been used extensively in the trade for this purpose.

5. Apparatus

5.1 *Testing Machines*—Machines used for tension testing shall conform to the requirements of Practices E 4. The forces used in determining tensile strength and yield strength shall be within the verified force application range of the testing machine as defined in Practices E 4.

5.2 Gripping Devices:

5.2.1 *General*—Various types of gripping devices may be used to transmit the measured load applied by the testing machine to the test specimens. To ensure axial tensile stress within the gage length, the axis of the test specimen must coincide with the centerline of the heads of the testing machine. Any departure from this requirement may introduce bending stresses that are not included in the usual stress computation (load divided by cross-sectional area).

NOTE 3—The effect of this eccentric loading may be illustrated by calculating the bending moment and stress thus added. For a standard 0.500-in. diameter specimen, the stress increase is 1.5 percentage points

*A Summary of Changes section appears at the end of this standard.

for each 0.001 in. of eccentricity. This error increases to 2.24 percentage points/0.001 in. for a 0.350-in. diameter specimen and to 3.17 percentage points/0.001 in. for a 0.250-in. diameter specimen.

NOTE 4—Alignment methods are given in Practice E 1012.

5.2.2 Wedge Grips—Testing machines usually are equipped with wedge grips. These wedge grips generally furnish a satisfactory means of gripping long specimens of ductile metal. If, however, for any reason, one grip of a pair advances farther than the other as the grips tighten, an undesirable bending stress may be introduced. When liners are used behind the wedges, they must be of the same thickness and their faces must be flat and parallel. For best results, the wedges should be supported over their entire length by the heads of the testing machine. This requires that liners of several thicknesses be available to cover the range of specimen thickness. For proper gripping, it is desirable that the entire length of the serrated face of each wedge be in contact with the specimen. Proper alignment of wedge grips and liners is illustrated in Fig. 1. For short specimens it is generally necessary to use machined test specimens and to use a special means of gripping to ensure that the specimens, when under load, shall be as nearly as possible in uniformly distributed pure axial tension (see 5.2.3, 5.2.4, and 5.2.5).

5.2.3 Grips for Threaded and Shouldered Specimens—A schematic diagram of a gripping device for threaded-end specimens is shown in Fig. 2, while Fig. 3 shows a device for gripping specimens with shouldered ends. Both of these gripping devices should be attached to the heads of the testing machine through properly lubricated spherical-seated bearings. The distance between spherical bearings should be as great as feasible.

5.2.4 Grips for Sheet Materials—The self-adjusting grips shown in Fig. 4 have proved satisfactory for testing sheet materials that cannot be tested satisfactorily in the usual type of wedge grips.

5.2.5 Grips for Wire—Grips of either the wedge or snubbing types as shown in Fig. 4 and Fig. 5 or flat wedge grips may be used.

5.3 Dimension-Measuring Devices—Micrometers and other devices used for measuring linear dimensions shall be accurate and precise to at least one half the smallest unit to which the individual dimension is required to be measured.

5.4 Extensometers—Extensometers used in tensile testing shall conform to the requirements of Practice E 83 for the classifications specified by the procedure section of these test methods. Extensometers shall be used and verified to include the strains corresponding to the yield strength and elongation at fracture (if determined).

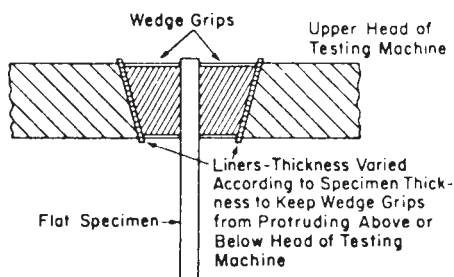


FIG. 1 Wedge Grips with Liners for Flat Specimens

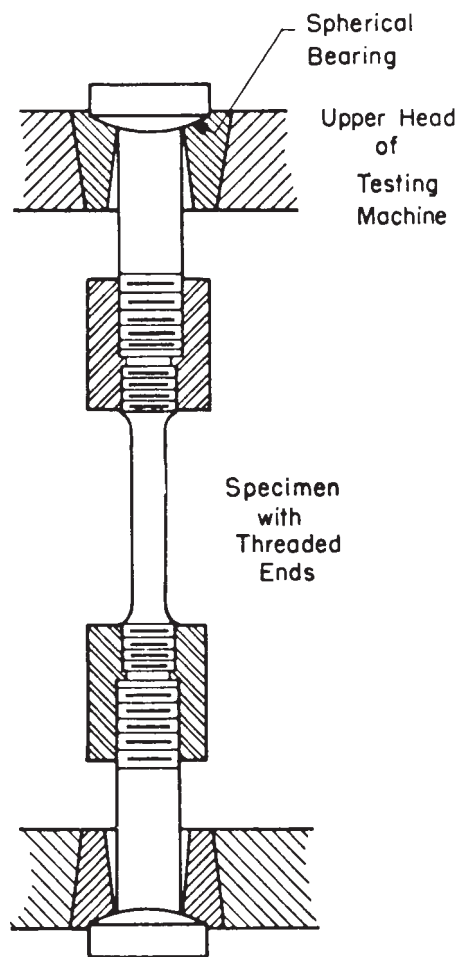


FIG. 2 Gripping Device for Threaded-End Specimens

5.4.1 Extensometers with gage lengths equal to or shorter than the nominal gage length of the specimen (dimension shown as “G-Gage Length” in the accompanying figures) may be used to determine the yield behavior. For measuring elongation at fracture with an appropriate extensometer, the gage length of the extensometer shall be equal to the nominal gage length required for the specimen being tested.

6. Test Specimen

6.1 General:

6.1.1 Test specimens shall be of the full section of the material whenever practical. Otherwise, machined specimens of rectangular or round cross section shall be used.

6.1.2 Improperly prepared test specimens often are the reason for unsatisfactory and incorrect test results. It is important, therefore, that care be exercised in the preparation of specimens, particularly in the machining, to ensure the desired precision and bias in test results.

6.1.3 The cross-sectional area of the specimen should be smallest at the center of the reduced section to ensure fracture within the gage length. For this reason, a small taper is permitted in the reduced section of each of the specimens described in the following sections.

6.1.4 Rectangular specimens shall be 0.500 in. wide in accordance with Fig. 6 or Fig. 7 (for tubular products), and

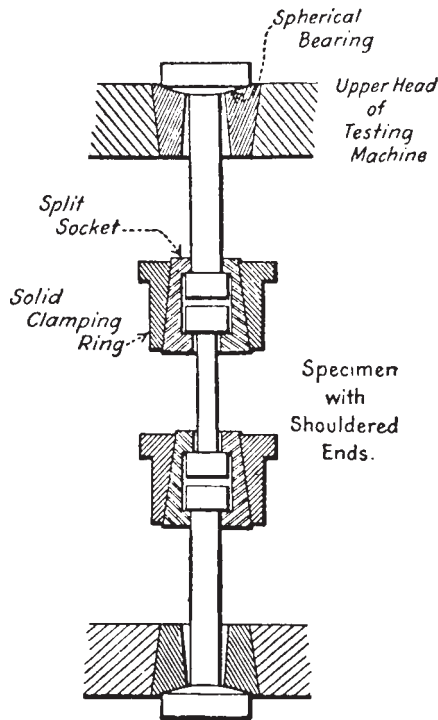


FIG. 3 Gripping Device for Shouldered-End Specimens

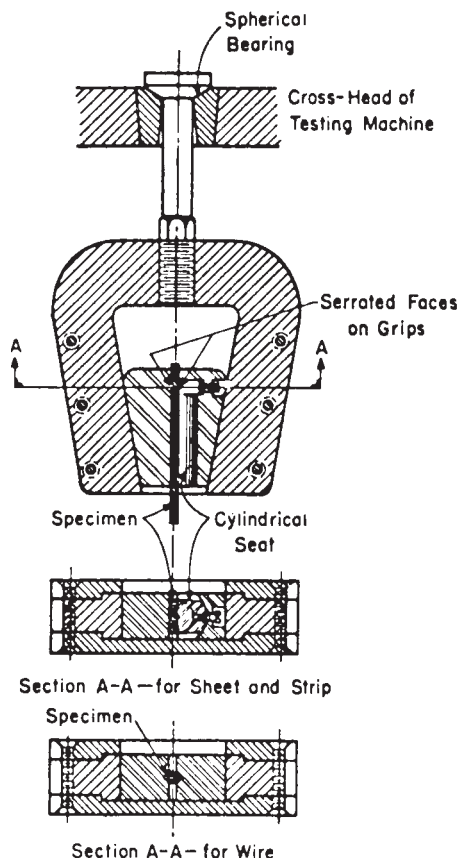


FIG. 4 Gripping Devices for Sheet and Wire Specimens

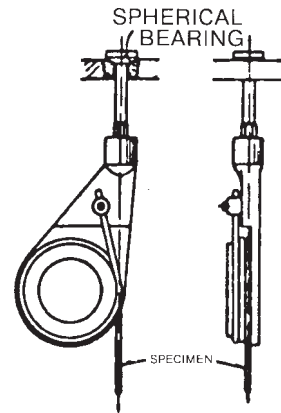


FIG. 5 Snubbing Device for Testing Wire

Fig. 6 may be used, but elongation values from such specimens are not applicable to specification requirements.

6.1.4.1 Pin ends as shown in Fig. 8 may be used. In order to avoid buckling in tests of thin and high-strength materials, it may be necessary to use stiffening plates at the grip ends.

6.1.5 Round specimens shall be the standard 0.500-in. diameter specimen in Fig. 9, except when the dimensions of the product make this impossible. In such cases, small-size specimens proportional to the standard specimen shown in Fig. 9 may be used. Unless otherwise specified in the product specification, the selection of round tension specimens shall be as specified in Table 1. Unless permitted by the product specification, the dimensions of the smallest specimen used shall not be less than the following:

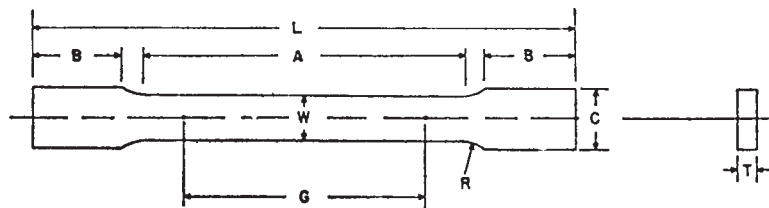
	Wrought	Cast
Diameter of reduced section, in.	0.160	0.250
Length of reduced section, in.	$\frac{3}{4}$	$1\frac{1}{4}$
Radius of fillet, in.	$\frac{1}{8}$	$\frac{3}{16}$
Diameter of end section, in.	$1\frac{5}{64}$	$\frac{3}{8}$
Overall length, in.		
With shouldered ends	$1\frac{1}{2}$	$2\frac{3}{8}$
With threaded ends	2	3
With plain cylindrical ends	3	4

6.1.5.1 The shape of the ends of the specimens outside of the gage length shall be suitable to the material and of a shape to fit the holders or grips of the testing machine so that the loads are applied axially. Fig. 10 shows specimens with various types of ends that have given satisfactory results.

6.1.6 Special care is required in the manufacture and testing of smaller specimens because the effects of machining (for example, the amount of end load applied and the amount of heat generated) and testing (for example, eccentricity and gage marking) variables are greater upon them than upon larger specimens. Therefore, the largest practical specimen shall always be used. With some types of materials, notably castings, the result of tests of small specimens may be more variable due to the increasing significance of variations in metallic structure or the character of the surfaces. Low values derived from small specimens should be carefully evaluated in accordance with 8.1 to be certain that the results are valid.

6.1.7 While tensile strengths and yield strengths can properly be compared with results derived from test specimens of various dimensions, elongation values may vary with specimen size and type. Therefore, elongation values should be obtained

shall be of the full thickness of the material when practical. When necessary, 0.250-in. wide subsize specimens as shown in



Dimensions, in.

	Standard Specimen Sheet-Type, 1/2-in. Wide	Subsize Specimen 1/4-in. Wide
G—Gage length	2.000 ± 0.005	1.000 ± 0.003
W—Width (Note 1 and Note 2)	0.500 ± 0.010	0.250 ± 0.002
T—Thickness (Note 3)	thickness of material	thickness of material
R—Radius of fillet, min	1/2	1/4
L—Overall length, min (Note 4)	8	4
A—Length of reduced section, min	2 1/4	1 1/4
B—Length of grip section, min (Note 5)	2	1 1/4
C—Width of grip section, approximate (Note 2 and Note 6)	3/4	3/8

NOTE 1—The ends of the reduced section shall not differ in width by more than 0.002 in. for the 2.00-in. gage length specimen or 0.001 in. for the 1.00-in. gage length specimen. There may be a gradual taper in width from the ends of the reduced section to the center, but the width at each end shall not be more than 1 % greater than the width at the center.

NOTE 2—For each of the specimens, narrower widths (*W* and *C*) may be used when necessary. In such cases the width of the reduced section should be as large as the width of the material being tested permits; however, unless stated specifically, the requirements for elongation in a product specification shall not apply when these narrower specimens are used. If the width of the material is less than *W*, the sides may be parallel throughout the length of the specimen.

NOTE 3—The dimension *T* is the thickness of the test specimen as stated in the applicable material specifications. Maximum nominal thicknesses of 1/2-in. and 1/4-in. wide specimens shall be 1/2 in. and 1/4 in., respectively.

NOTE 4—To aid in obtaining axial loading during testing of 1/4-in. wide specimens, the overall length should be as large as the material will permit, up to 8 in.

NOTE 5—It is desirable, if possible, to make the length of the grip section large enough to allow the specimen to extend into the grips a distance equal to two thirds or more of the length of the grips. If the thickness of 1/2-in. wide specimens is over 3/8 in., longer grips and correspondingly longer grip sections of the specimen may be necessary to prevent failure in the grip section.

NOTE 6—The grip-end centerline of the 1/2-in. wide and 1/4-in. wide specimens shall coincide with the centerline of the reduced section within 0.01 and 0.005 in., respectively.

FIG. 6 Rectangular Tension Test Specimens

with specimens of the type from which the published tensile properties were established.

6.2 Type, Direction, and Location in Wrought Products—This paragraph and subparagraphs provide the standard requirements for the testing of wrought products for the purpose of quality control and lot release testing. Additions or exceptions to these requirements may need to be made in individual specifications for a particular material or product

NOTE 5—These requirements also do not preclude the use of these test methods for purposes other than quality control as desired for research, material evaluation, or other purpose utilizing other test locations, test directions, and test specimen sizes. In these cases, the general requirements in 6.1 should be followed for specimen type and the requirements in Sections 5 and 7 shall be followed for test apparatus, testing, and analysis.

6.2.1 Sheet and Plate:

6.2.1.1 Rectangular specimens shall be used for thicknesses less than 0.500 in., and round specimens for all others.

6.2.1.2 For thicknesses 0.500 in. through 1.500 in., inplane specimens shall be taken from the center of the thickness; for larger thicknesses, they shall be taken midway from the center

to the surface. Short transverse specimens shall be taken so that the midpoint of their axis lies on the plate mid-thickness.

6.2.1.3 For non-heat-treatable aluminum alloys, specimens shall be taken parallel to the direction of rolling.

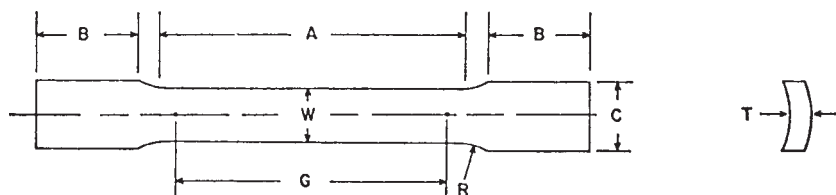
6.2.1.4 For heat-treatable aluminum alloys, specimens shall be taken perpendicular to the direction of rolling (long-transverse), unless otherwise specified in the material specification. For widths too narrow for long-transverse standard rectangular or 0.500-in. diameter specimens, specimens shall be taken parallel to the direction of rolling.

6.2.1.5 For magnesium alloys, specimens shall be taken parallel to the direction of rolling.

6.2.2 Wire, Rod, and Bar:

6.2.2.1 Full-section specimens shall be used when practical. It is permissible to reduce the section slightly throughout the test section in order to ensure fracture within the gage length. Otherwise, round specimens shall be used, except that for rectangles less than 0.500-in. thick rectangular specimens of the full thickness may be used.

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	Dimensions, in.
G—Gage length	2.000 ± 0.005
W—Width (Note 1)	0.500 ± 0.010
T—Measured thickness of specimen	Note 2
R—Radius of fillet, min	$\frac{1}{2}$
A—Length of reduced section, min	$2\frac{3}{4}$
B—Length of grip section, min (Note 3)	3
C—Width of grip section, approximate (Note 4)	$1\frac{1}{16}$

NOTE 1—The ends of the reduced section shall not differ in width by more than 0.002 in. There may be a gradual taper in width from the ends of the reduced section to the center, but the width at each end shall not be more than 1 % greater than the width at the center.

NOTE 2—The dimension *T* is the thickness of the tubular section as provided for in the applicable material specifications.

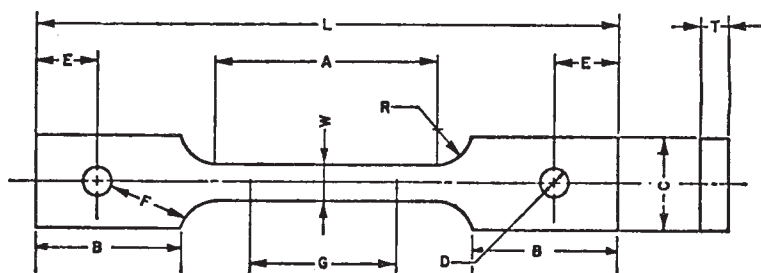
NOTE 3—It is desirable, if possible, to make the length of the grip section great enough to allow the specimen to extend into the grips a distance equal to two thirds or more of the length of the grips.

NOTE 4—The grip-end centerline of the specimen shall coincide with the centerline of the reduced section within 0.05 in.

NOTE 5—For circular segment, the cross-sectional area shall be calculated using the formula shown in 7.2.3

NOTE 6—The radii of all fillets shall be equal to each other within a tolerance of 0.05 in., and the centers of curvature of the two fillets at a particular end shall be located across from each other (on a line perpendicular to the centerline) within a tolerance of 0.10 in.

FIG. 7 Longitudinal Tension Test Specimens for Large-Diameter Tubular Products



	Dimensions, in.
G—Gage length	2.000 ± 0.005
W—Width (Note 1)	0.500 ± 0.010
T—Thickness, max (Note 2)	$\frac{5}{8}$
R—Radius of fillet, min (Note 3)	$\frac{1}{2}$
L—Overall length, min	8
A—Length of reduced section, min	$2\frac{3}{4}$
B—Length of grip section, min	2
C—Width of grip section, approximate	2
D—Diameter of hole for pin, min (Note 4)	$\frac{1}{2}$
E—Edge distance from pin, approximate	$1\frac{1}{2}$
F—Distance from hole to fillet, min	$\frac{1}{2}$

NOTE 1—The ends of the reduced section shall differ in width by not more than 0.002 in. There may be a gradual taper in width from the ends of the reduced section to the center, but the width at each end shall be not more than 1 % greater than the width at the center.

NOTE 2—The dimension *T* is the thickness of the test specimen as stated in the applicable product specifications.

NOTE 3—For some materials, a fillet radius *R* larger than $\frac{1}{2}$ in. may be needed.

NOTE 4—Holes must be on centerline of reduced section, within ± 0.002 in.

NOTE 5—Variations of dimensions *C*, *D*, *E*, *F*, and *L* may be used that will permit failure within the gage length.

FIG. 8 Pin-Loaded Tension Test Specimen with 2-in. Gage Length

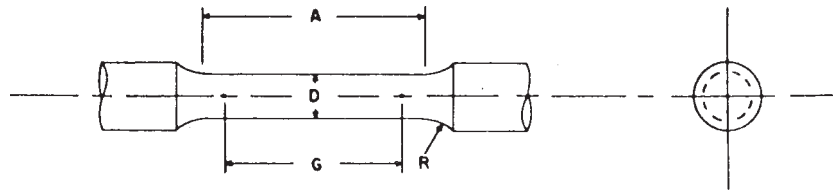
6.2.2.2 Specimens shall be taken in the longitudinal direction from the locations specified in Table 2.

6.2.3 Extrusion Profiles:

6.2.3.1 Round specimens shall be used whenever it is not practical to use full-section specimens, except that for extrusion profiles less than 0.500 in. thick, rectangular specimens may be used.

6.2.3.2 Specimens shall be taken in the longitudinal direction from the predominant section of the extrusion profile. The specimens shall be taken from a location that most nearly satisfies the intent of Table 2.

6.2.4 *Tube and Pipe*—Specimens shall be taken in the longitudinal direction.



Nominal Diameter	Dimensions, in.			
	Standard Specimen	Small-Size Specimens Proportional to Standard		
	0.500	0.350	0.250	0.160
G—Gage length	2.000 ± 0.005	1.400 ± 0.005	1.000 ± 0.005	0.640 ± 0.005
D—Diameter (Note 1)	0.500 ± 0.010	0.350 ± 0.007	0.250 ± 0.005	0.160 ± 0.003
R—Radius of fillet, min	3/8	1/4	3/16	5/32
A—Length of reduced section, min (Note 2)	2 1/4	1 3/4	1 1/4	3/4

NOTE 1—The reduced section may have a gradual taper from the ends toward the center, with the ends not more than 1 % larger in diameter than the center (controlling dimension).

NOTE 2—If desired, the length of the reduced section may be increased to accommodate an extensometer of any convenient gage length. Reference marks for the measurement of elongation should, nevertheless, be spaced at the indicated gage length.

NOTE 3—The gage length and fillets shall be as shown, but the ends may be of any form to fit the holders of the testing machine in such a way that the load shall be axial (see Fig. 10). If the ends are held in wedge grips it is desirable, if possible, to make the length of the grip section great enough to allow the specimen to extend into the grips a distance equal to two thirds or more of the length of the grips.

NOTE 4—On the round specimens in Fig. 9 and Fig. 10, the gage lengths are equal to four times the nominal diameter. In some product specifications other specimens may be provided for, but unless the 4-to-1 ratio is maintained within dimensional tolerances, the elongation values may not be comparable with those obtained from the standard test specimen.

NOTE 5—The use of specimens smaller than 0.250-in. diameter shall be restricted to cases when the material to be tested is of insufficient size to obtain larger specimens or when all parties agree to their use for acceptance testing. Smaller specimens require suitable equipment and greater skill in both machining and testing.

NOTE 6—Four sizes of specimens often used have diameters of approximately 0.505, 0.357, 0.252, and 0.160 in., the reason being to permit easy calculations of stress from loads, since the corresponding cross-sectional areas are equal or close to 0.200, 0.100, 0.0500, and 0.0200 in.², respectively. Thus, when the actual diameters agree with these values, the stresses (or strengths) may be computed using the simple multiplying factors 5, 10, 20, and 50, respectively.

FIG. 9 Standard 0.500-in. Round Tension Test Specimen with 2-in. Gage Length and Examples of Small-Size Specimens Proportional to the Standard Specimen

TABLE 1 Guidelines for Selecting Round Tensile Specimens

Specified Material Thickness, in	Minimum Material Section Thickness Length or Width, in	Specimen Diameter, in
0.250 through 0.374	1 1/2	0.160
0.375 through 0.499	2 1/2	0.250
0.500 through 0.624	3 3/4	0.350
0.625 and over	4 3/4	0.500

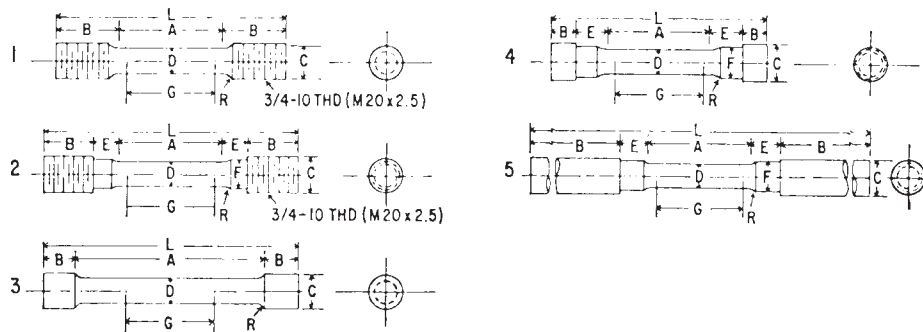
6.2.4.1 For all small tube (Note 6), particularly sizes 1 in. and under in nominal outside diameter, and frequently for larger sizes, except as limited by the testing equipment, it is standard practice to use tension test specimens of full-size tubular sections. Snug-fitting metal plugs shall be inserted far enough into the ends of such tubular specimens to permit the testing machine jaws to grip the specimens properly. The plugs shall not extend into that part of the specimen on which the elongation is measured. Fig. 11 shows a suitable form of plug, the location of the plugs in the specimen, and the location of the specimen in the grips of the testing machine.

NOTE 6—The term “tube” is used to indicate tubular products in general, and includes pipe, tube, and tubing.

6.2.4.2 When it is not practical to test full-section specimens, 0.500-in. wide specimens in accordance with Fig. 7 taken as in Fig. 12 shall be used if practical. Otherwise, round specimens in accordance with 6.1.5 shall be taken from the

center of wall thicknesses through 1.500 in.; for thicknesses over 1.500 in., they shall be taken midway from center of thickness to surface. If specimens of the type shown in Fig. 7 are used and curved grip faces are not available, it is acceptable to flatten (without heating) the grip ends of the test specimen. The gage length area shall not be deformed.

6.2.5 *Die Forgings*—Round specimens shall be used for section thicknesses 0.500 in. and greater. Either subsize round or rectangular specimens may be used for section thicknesses from 0.312 to 0.499 in. Rectangular specimens shall be used for section thicknesses less than 0.312 in. The direction of the specimens shall be in the longitudinal grain direction, unless specimens in other directions are required. For aluminum die forgings, the longitudinal grain direction is defined as orientations parallel, within ±15°, to the predominate grain flow. The long transverse grain direction is defined as perpendicular, within ±15°, to the longitudinal (predominate) grain direction and parallel, within ±15°, to the parting plane. (Both conditions must be met.) The short transverse grain direction is defined as perpendicular, within ±15°, to the longitudinal (predominate) grain direction and perpendicular, within ±15°, to the parting plane. Specimens shall be taken from the center of the predominant or thickest part of the forging from which a coupon can be obtained, from a prolongation of the forging, or from separately forged coupons from the same stock and representative of the forging.



	Dimensions, in.				
	Specimen 1	Specimen 2	Specimen 3	Specimen 4	Specimen 5
<i>G</i> —Gage length	2.000 ± 0.005	2.000 ± 0.005	2.000 ± 0.005	2.000 ± 0.005	2.000 ± 0.005
<i>D</i> —Diameter (Note 1)	0.500 ± 0.010	0.500 ± 0.010	0.500 ± 0.010	0.500 ± 0.010	0.500 ± 0.010
<i>R</i> —Radius of fillet, min	⅜	⅜	⅛ ₁₆	⅜	⅜
<i>A</i> —Length of reduced section	2¼, min	2¼, min	4, approximately	2¼, min	2¼, min
<i>L</i> —Overall length, approximate	5	5½	5½	4¾	3½
<i>B</i> —Length of end section (Note 2)	1⅜, approximately	1, approximately	¾ approximately	½, approximately	3, min
<i>C</i> —Diameter of end section	¾	¾	2¾ ₃₂	7⁄8	¾
<i>E</i> —Length of shoulder and fillet section, approximate	...	⅝	...	¾	⅝
<i>F</i> —Diameter of shoulder	...	⅝	...	⅝	1⁹⁄ ₃₂

NOTE 1—The reduced section may have a gradual taper from the ends toward the center with the ends not more than 0.005 in. larger in diameter than the center.

NOTE 2—On Specimen 5 it is desirable, if possible, to make the length of the grip section great enough to allow the specimen to extend into the grips a distance equal to two thirds or more of the length of the grips.

FIG. 10 Various Types of Ends for Standard Round Tension Test Specimen

TABLE 2 Location of Axis of Specimens in Rod, Bar, and Extrusion Profiles

Section Diameter, Thickness or Width, in.	Location of Axis of Specimen with Respect to Thickness (<i>T</i>) and Width (<i>W</i>) of Bar and Shapes or Diameter (<i>D</i>) of Rod		
	Thickness	Width	Diameter
Up through 1.500, incl	<i>T</i> /2	<i>W</i> /2	<i>D</i> /2
Over 1.500	<i>T</i> /4	<i>W</i> /4	<i>D</i> /4

6.2.6 *Hand Forgings*—Round specimens shall be used. They shall be taken in the long-transverse direction, and when specified, in the longitudinal and short-transverse directions. A longitudinal specimen shall be taken so that its axis coincides with the longitudinal centerline of the forging. A long-transverse or short-transverse specimen shall be taken so that the midpoint of its axis lies on the longitudinal centerline of the forging. Each specimen shall be so chosen that the distance from the midpoint of its axis to the end of the forging is at least half the thickness of the forging.

6.3 Type of Specimen from Castings:

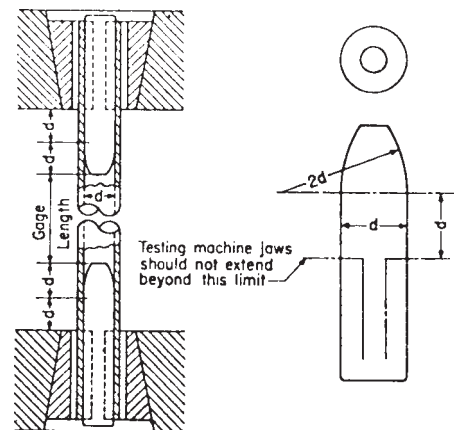
6.3.1 Test specimens shall be separately cast or, if called for by product specification or customer requirements, machined from the casting itself.

6.3.2 *Cast Test Specimens*—Cast test specimens shall be prepared in accordance with the appropriate product specification.

6.3.3 Specimens Machined from Castings:

6.3.3.1 Round specimens in accordance with Fig. 9 shall be used for section thicknesses 0.500 in. and greater.

6.3.3.2 Either small-size round specimens proportional to the standard specimen in Fig. 9 or rectangular specimens in



NOTE 1—The diameter of the plug shall have a slight taper from the line limiting the testing machine jaws to the curved section.

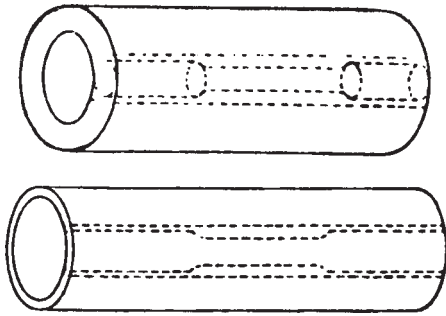
FIG. 11 Metal Plugs for Testing Tubular Specimens, Proper Location of Plugs in Specimen, and of Specimen in Heads of Testing Machine

accordance with Fig. 6 may be used for section thicknesses from 0.312 to 0.499 in., except as limited by 6.1.3.

6.3.3.3 Rectangular specimens in accordance with Fig. 6 shall be used for section thicknesses less than 0.312 in.

6.3.3.4 All test specimens must have a machined finish of 63 $\mu\text{in. RMS}$ (57 $\mu\text{in. AA}$) or smoother.

6.4 *Specimen for Die Castings*—For testing die castings the test specimen shown in Fig. 13 shall be used unless otherwise provided in the product specifications.



NOTE 1—The edges of the specimen shall be cut parallel to each other.

FIG. 12 Location from Which Longitudinal Tension Test Specimens Are to Be Cut from Large-Diameter Tube

6.5 *Specimens for Powdered Metals*—For testing powdered metals the test specimens shown in Fig. 14 and Fig. 15 shall be used, unless otherwise provided in the product specifications.

7. Procedure

7.1 *Preparation of the Test Machine*—Upon startup, or following a prolonged period of machine inactivity, exercise or warmup the test machine to normal operating temperatures to minimize errors that may result from transient conditions.

7.2 Measurement of Dimensions of Test Specimens:

7.2.1 To determine the cross-sectional area of a tension test specimen, measure the dimensions of the cross section at the center of the reduced section. However, for referee testing of specimens under $\frac{3}{16}$ in. in their least dimension, measure the dimensions where the least cross-sectional area is found. Measure and record the cross-sectional dimensions of tension test specimens 0.200 in. and over to the nearest 0.001 in.; the cross-sectional dimensions less than 0.200 in. and not less than 0.100 in. to the nearest 0.0005 in.; the cross-sectional dimensions less than 0.100 in. and not less than 0.020 in., to the nearest 0.0001 in.; and when practical, the cross-sectional dimensions less than 0.020 in., to at least the nearest 1 % but in all cases to at least the nearest 0.0001 in.

NOTE 7—Measurements of dimensions presume smooth surface finishes for the specimens. Rough surfaces due to the manufacturing process such as hot rolling, metallic coating, and so forth, may lead to inaccuracy of the computed areas greater than the measured dimensions would indicate. Therefore, cross-sectional dimensions of tension test specimens with rough surfaces due to processing may be measured and recorded to the nearest 0.001 in.

7.2.2 Determine cross-sectional areas of full-size tension test specimens of nonsymmetrical cross sections by weighing a length not less than 20 times the largest cross-sectional dimension and using the value of density of the material. Determine the weight to the nearest 0.5 % or less.

7.2.3 When using specimens of the type shown in Fig. 7 taken from tubes, determine the cross-sectional area as follows:

If $D/W \leq 6$:

$$A = [(W/4) \times (D^2 - W^2)^{1/2}] + [(D^2/4) \times \arcsin(W/D)] - [(W/4) \times ((D - 2T)^2 - W^2)^{1/2}] - [((D - 2T)/2)^2 \times \arcsin(W/(D - 2T))] \quad (1)$$

where:

A = exact cross-sectional area, in.²,

W = width of the specimen in the reduced section, in.,

D = measured outside diameter of the tube, in., and

T = measured wall thickness of the specimen, in. arcsin values to be in radians.

If $D/W > 6$, the exact equation or the following equation may be used:

$$A = W \times T \quad (2)$$

where:

A = approximate cross-sectional area, in.²,

W = width of the specimen in the reduced section, in., and

T = measured wall thickness of the specimen, in.

7.3 Gage Length Marking of Test Specimens:

7.3.1 The gage length for the determination of elongation after fracture shall be in accordance with the product specifications for the material being tested. Gage marks shall be stamped lightly with a punch, scribed lightly with dividers, or drawn with ink as preferred. For material that is sensitive to the effect of slight notches and for small specimens, the use of layout ink will aid in locating the original gage marks after fracture.

7.3.2 In the absence of a product specification, the following gage lengths shall be used:

7.3.2.1 For $\frac{1}{2}$ -in. wide rectangular specimens and full-section specimens from tube and pipe, the gage lengths shall be 2 in. (Figs. 6-8, and Fig. 11).

7.3.2.2 For round specimens taken from products 0.125 in. or larger, the gage length shall be 4D, except for wire for electric conductors (Fig. 9).

7.3.2.3 For wire for electric conductors the gage length shall be 10 in.

7.3.2.4 For die cast specimens, the gage length shall be 8D (Fig. 13).

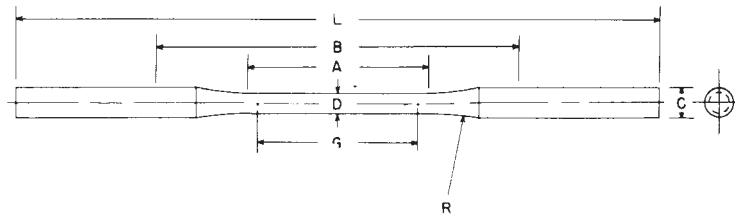
7.3.2.5 For powdered metal specimens, the gage length shall be 1 in. (Figs. 14 and 15).

7.3.2.6 Elongation measurements are not required for extrusion profiles less than 0.062 in. in thickness and of wire, other than electric conductors, 0.125 in. and less in diameter.

7.3.3 When required by the material specification, or when making retests or referee tests of products other than wire when the specified elongation is less than 3 % or the elongation measured in a usual manner is less than 4 %, mark the original gage length of the specimen and measure to an accuracy of ± 0.002 in.

7.4 *Zeroing of the Test Machine*—The testing machine shall be set up in such a manner that zero force indication signifies a state of zero force on the specimen. Any force (or preload) imparted by the gripping of the specimen (see Note 8) must be indicated by the force measuring system unless the preload is physically removed prior to testing. Artificial methods of removing the preload on the specimen, such as taring it out by a zero adjust pot or removing it mathematically by software, are prohibited because these would affect the accuracy of the test results.

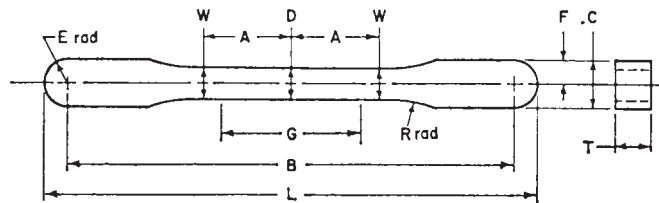
NOTE 8—Preloads generated by gripping of specimens may be either tensile or compressive in nature and may be the result of such things as: grip design, malfunction of gripping apparatus (sticking, binding, and so



	Dimensions, in.
G—Gage length	2.000 ± 0.005
D—Diameter (see Note)	0.250 ± 0.005
R—Radius of fillet, min	3
A—Length of reduced section, min	2¼
L—Overall length, min	9
B—Distance between grips, min	4½
C—Diameter of end section, approximate	¾

NOTE 1—The reduced section may have a gradual taper from the ends toward the center, with the ends not more than 0.005 in. larger in diameter than the center.

FIG. 13 Standard Tension Test Specimen for Die Castings



Pressing Area = 1.00 in.²
Dimensions Specified except G, are Those of the Die.

	Dimensions, in.
G—Gage length	1.000 ± 0.005
D—Width at center	0.225 ± 0.001
W—Width at end of reduced section	0.235 ± 0.001
T—Compact to this thickness	0.200 to 0.250
R—Radius of fillet	1
A—Half-length of reduced section	⅝
B—Grip length	3.187 ± 0.001
L—Overall length	3.529 ± 0.001
C—Width of grip section	0.343 ± 0.001
F—Half width of grip section	0.1715 ± 0.0010
E—End radius	0.171 ± 0.001

FIG. 14 Standard Tension Test Specimen for Powdered Metal Products—Flat Unmachined Tension Test Specimen

forth), excessive gripping force, and sensitivity of the control loop.

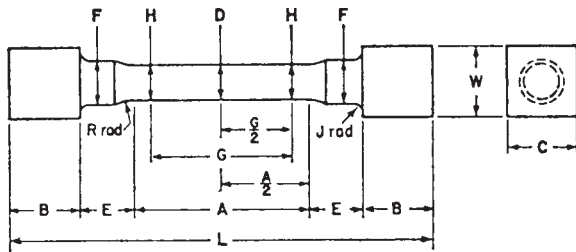
NOTE 9—It is the operator's responsibility to verify that an observed preload is acceptable and to ensure that grips operate in a smooth manner. Unless otherwise specified, it is recommended that momentary (dynamic) forces due to gripping not exceed 20 % of the material's nominal yield strength and that static preloads not exceed 10 % of the material's nominal yield strength.

7.5 Speed of Testing:

7.5.1 Speed of testing may be defined in terms of (a) free-running crosshead speed (rate of movement of the crosshead of the testing machine when not under load), (b) rate of separation of the two heads of the testing machine during a test, (c) the elapsed time for completing part or all of the test, (d) rate of stressing the specimen, or (e) rate of straining the specimen. For some materials, the first of these, which is the least accurate, may be adequate, while for other materials, one of the others, listed in increasing order of precision, may be

necessary in order to obtain test values within acceptable limits. Suitable limits for speed of testing should be specified for materials for which the differences resulting from the use of different speeds are of such magnitude that the test results are unsatisfactory for determining the acceptability of the material. In such instances, depending upon the material and the use for which it is intended, one or more of the methods described in the following paragraphs is recommended for specifying speed of testing.

7.5.2 *Free-Running Crosshead Speed*—The allowable limits for the rate of movement of the crosshead of the testing machine, with no force applied by the testing machine, shall be specified in inches per inch of length of reduced section (or distance between grips for specimens not having reduced sections) per minute. The limits for the crosshead speed may be further qualified by specifying different limits for various types



Pressing Area of Unmachined Compact = 1.5 in.²
Machining Recommendations

1. Rough machine to $\frac{5}{16}$ -in. diameter
2. Finish turn 0.250-in. diameter with radii and taper
3. Polish with 00 emery cloth
4. Lap with crocus cloth

	Dimensions, in.
G—Gage length	1.000 $\pm$ 0.005
D—Diameter at center of reduced section	0.250 $\pm$ 0.001
H—Diameter at ends of gage length	D + 0.001 to 0.002 in.
R—Radius of fillet	$\frac{1}{4}$
A—Length of reduced section	$1\frac{1}{4}$
L—Overall length (die cavity length)	3
B—Length of end section	$\frac{1}{2}$
C—Compact to this end thickness	0.500 $\pm$ 0.050
W—Die cavity width	$\frac{1}{2}$
E—Length of shoulder and fillet	$\frac{3}{8}$
F—Diameter of shoulder	$\frac{5}{16}$
J—End fillet radius, max	$\frac{1}{16}$

NOTE 1—The gage length and fillets of the specimen shall be as shown. The ends as shown are designed to provide a total pressing area of 1.00 in.² Other end designs are acceptable, and in some cases are required for high-strength sintered materials. Some suggested alternative end designs include:

1. Longer ends, of the same general shape and configuration as the standard, provide more surface area for gripping.
2. Shallow transverse grooves, or ridges, may be pressed in the ends to be gripped by jaws machined to fit the specimen contour.

FIG. 15 Standard Tension Test Specimen for Powdered Metal Products—Round Machined Tension Test Specimen

and sizes of specimens. The average crosshead speed can be experimentally determined by using a suitable measuring device and a timing device.

7.5.3 Rate of Separation of Heads During Tests—The allowable limits for rate of separation of the heads of the testing machine during a test shall be specified in inches per inch of length of reduced section (or distance between grips for specimens not having reduced sections) per minute. The limits for the rate of separation may be further qualified by specifying different limits for various types and sizes of specimens. Many testing machines are equipped with pacing or indicating devices for the measurement and control of the rate of separation of the heads of the machine during a test, but, in the absence of such a device, the average rate of separation of the heads can be experimentally determined by using a suitable length-measuring device and a timing device.

7.5.4 Elapsed Time—The allowable limits for the elapsed time from the beginning of force application (or from some specified stress) to the instant of fracture, to the maximum force, or to some other stated stress, shall be specified in minutes or seconds. The elapsed time can be determined with a timing device.

7.5.5 Rate of Stressing—The allowable limits for rate of stressing shall be specified in pounds per square inch per minute. Many testing machines are equipped with pacing devices for the measurement and control of the rate of stressing, but in the absence of such a device the average rate of stressing can be determined with a timing device by observing the time required to apply a known increment of stress.

7.5.6 Rate of Straining—The allowable limits for rate of straining shall be specified in inches per inch per minute. Some testing machines are equipped with pacing or indicating devices for the measurement and control of rate of straining, but, in the absence of such a device, the average rate of straining can be determined with a timing device by observing the time required to effect a known increment of strain.

7.5.7 Unless otherwise specified, any convenient speed of testing may be used up to one half the specified yield strength, or up to one quarter the specified tensile strength, whichever is smaller. The speed above this point shall be within the limits specified. If different speed limitations are required for use in determining yield strength, tensile strength, and elongation, they should be stated in the product specifications. In the absence of any more specified limitations on speed of testing the following general rules shall apply:

7.5.7.1 The speed of testing shall be such that the forces and strains used in obtaining the test results are accurately indicated.

7.5.7.2 During the conduct of the test to determine yield strength, the rate of stress application shall not exceed 100 000 psi/min. The speed may be increased after removal of the extensometer, but it shall not exceed 0.5 in./in. of gage length (or distance between grips for specimens not having reduced sections) per minute.

7.6 Yield Strength—Determine yield strength by the offset method at an offset of 0.2 %. Acceptance or rejection of material may be decided on the basis of Extension-Under-Load Method. For referee testing, the offset method shall be used.

7.6.1 Offset Method—To determine the yield strength by the “offset method,” it is necessary to secure data (autographic or numerical) from which a stress-strain diagram may be drawn. Then on the stress-strain diagram (Fig. 16) lay off O_m equal to the specified value of the offset, draw mn parallel to OA , and thus locate r , the intersection of mn with the stress-strain diagram (Note 10). In reporting values of yield strength obtained by this method, the specified value of “offset” used should be stated in parentheses after the term yield strength. Thus:

$$\text{Yield strength (offset = 0.2 \%)} = 52\ 000 \text{ psi} \quad (3)$$

A Class B2 extensometer (see Practice E 83) would be sufficiently sensitive for most materials when using this method.

NOTE 10—Automatic devices are available that determine offset yield strength without plotting a stress-strain curve. Such devices may be used if their accuracy has been demonstrated to be satisfactory.

NOTE 11—If the force drops before the specified offset is reached, technically the material does not have a yield strength (for that offset), but the stress at the maximum force attained before the specified offset is reached may be reported instead of the yield strength.

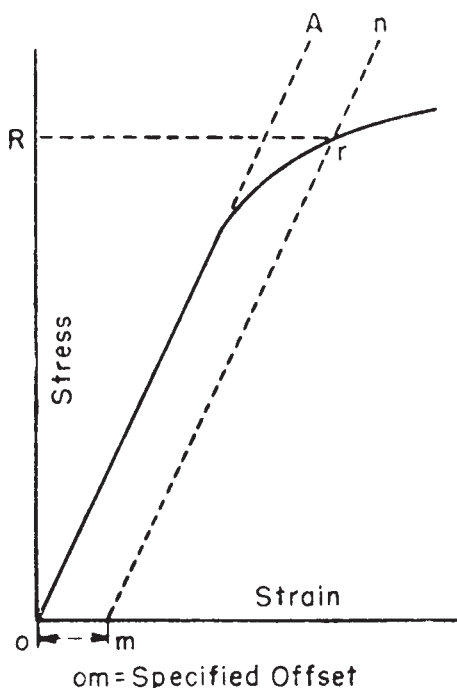


FIG. 16 Stress-Strain Diagram for Determination of Yield Strength by the Offset Method

7.6.2 *Extension-Under-Load Method*—For tests to determine the acceptance or rejection of material whose stress-strain characteristics are well-known from previous tests of similar material in which stress-strain diagrams were plotted, the total strain corresponding to the stress at which the specified offset occurs will be known within satisfactory limits; therefore, in such tests a specified total strain may be used, and the stress on the specimen, when this total strain is reached, is taken to be the value of the yield strength (Fig. 17). The total strain can be obtained satisfactorily by use of a Class B2 extensometer. It is recommended that this approximate method be used only after agreement between the manufacturer and the purchaser, with

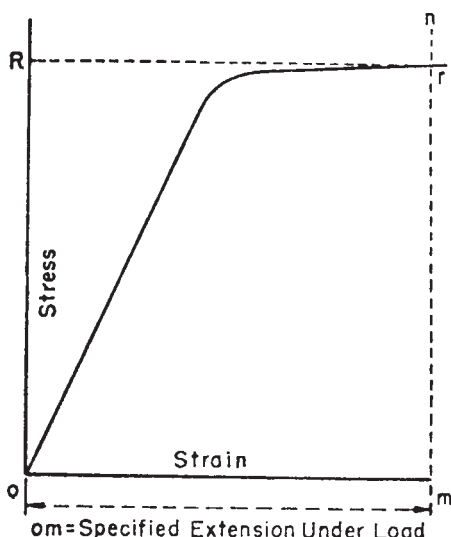


FIG. 17 Stress-Strain Diagram for Determination of Yield Strength by the Extension-Under-Load Method

the understanding that check tests be made for obtaining stress-strain diagrams for use with the offset method to settle any misunderstandings.

NOTE 12—There are two general types of extensometers, averaging and non-averaging, the use of which is dependent on the product tested. For most machined or reduced section specimens; there are minimal differences. However, for some materials such as some forgings and tube sections, significant differences in measured yield strength can occur. For these cases it is recommended that the averaging type be used.

7.7 *Tensile Strength*—Calculate the tensile strength by dividing the maximum load carried by the specimen during a tension test by the original cross-sectional area of the specimen.

7.8 *Elongation:*

7.8.1 To determine elongation after fracture, carefully fit ends of the fractured specimen together and measure the distance between the gage marks to the nearest 0.01 in. A percentage scale reading to 0.5 % of the gage length may be used. The elongation after fracture is the increase in length of the gage length, expressed as a percentage of the original gage length. Report the elongation after fracture using both the percentage increase and the original gage length.

7.8.2 If any part of the fracture takes place outside of the middle half of the gage length or in a punched or scribed mark within the reduced section, the elongation value obtained may not be representative of the material. If the elongation so measured meets the minimum requirements specified, no further testing is required, but the location of fracture shall be noted. If the elongation is less than the minimum requirements, discard the test and test a replacement specimen as allowed in 8.1.

7.8.3 Elongation at fracture is defined as the elongation measured just prior to the sudden decrease in force associated with fracture. For many ductile materials not exhibiting a sudden decrease in force, the elongation at fracture can be taken as the strain measured just prior to when the force falls below 10 % of the maximum force encountered during the test.

7.8.3.1 Elongation at fracture shall include elastic and plastic elongation and may be determined with autographic or automated methods using extensometers verified over the strain range of interest (see 5.4). Use a Class B2 or better extensometer for materials having less than 5 % elongation, a Class C or better extensometer for materials having elongation greater than or equal to 5 % but less than 50 %, and a Class D or better extensometer for materials having 50 % or greater elongation. In all cases, the extensometer gage length shall be the nominal gage length required for the specimen being tested. Due to the lack of precision in fitting fractured ends together, the elongation after fracture using the manual methods of the preceding paragraphs may differ from the elongation at fracture determined with extensometers.

7.8.3.2 Percent elongation at fracture may be calculated directly from elongation at fracture data and reported instead of percent elongation after fracture as calculated in 7.8.1 and 7.8.2. However, the two parameters are not interchangeable. Use of the elongation at fracture method generally provides more repeatable results.

NOTE 13—When disagreements arise over the percent elongation results, agreement must be reached on which method to use.

7.8.4 When required by the material specification, or when making retests or for referee tests of products other than wire and the specified elongation is less than 3 % or the elongation measured in the usual manner is less than 4 %, determine the elongation of a specimen as follows:

7.8.4.1 Prior to testing, the original gage length of the specimen shall be marked and measured to an accuracy of ± 0.002 in. as required in 7.3.3

7.8.4.2 After testing, remove any partly torn fragments that might influence the final measurement from the broken ends of the specimen.

7.8.4.3 Fit the fractured ends together with matched surfaces and apply an end load along the axis of the specimen sufficient to close the fractured ends together. If desired, this load may then be removed carefully, provided the specimen remains intact.

NOTE 14—The use of an end load of approximately 2000 psi has been found to give satisfactory results on test specimens of aluminum alloy.

7.8.4.4 Measure the final gage length to at least the nearest 0.002 in., and report the elongation to at least the nearest 0.1 % in 2 in. or 0.2 % in shorter gage lengths.

7.9 *Rounding*—Round each value of strength to the nearest 0.1 ksi. Round each value of elongation determined in accordance with 7.8.1 to the nearest 0.5 %, unless otherwise specified. Round in accordance with Practice E 29.

7.9.1 If elongation is determined in accordance with 7.8.4, round each value in accordance with 7.8.4.4.

7.9.2 For wire for electric conductors, measure and report the elongation to the nearest 0.1 %.

8. Replacement Tests

8.1 A test specimen may be discarded and a replacement specimen selected from the same lot of material when (1) the specimen had a poorly machined surface, was not of the proper dimensions, or had its properties changed by poor machining practice; (2) the test procedure was incorrect or the test equipment malfunctioned; or (3) the fracture was outside the middle half of the gage length, and the elongation was below the specified value.

8.2 In the case of specimens machined from wrought products or castings, discontinuities such as cracks, ruptures, flakes and porosity revealed in the fracture that are considered indicative of inferior or defective material are not reasons for the selection of a replacement test specimen.

8.3 In the case of separately cast test specimens, flaws other than gas porosity, such as cracks or inclusions, are not the cause of rejection of the castings based upon tensile properties, and so the presence of such flaws in the fracture is justification for replacement testing.

9. Retests

9.1 If one or more test specimens fail to conform to the requirements of the product specification, the lot represented by the specimen or specimens shall be subject to rejection except as provided as follows.

9.2 If a material lot is subject to rejection, retests of that lot will be permitted by:

9.2.1 Testing, for each specimen that failed, at least two additional specimens from an area in the original sample adjacent to the area represented by the failure or failures, or

9.2.2 Testing an additional specimen from the specified location in each of at least two other samples for each sample that failed from the same lot.

9.2.3 In the case of separately cast test specimens, testing two additional cast specimens from the same lot for each specimen that failed.

9.3 If any retest fails, the lot shall be subject to rejection, except that the lot may be resubmitted for testing provided the producer has reworked the lot, as necessary, to correct the deficiencies or has removed the nonconforming material.

10. Report

10.1 Report test information on materials not covered by a product specification in accordance with 10.2 or both 10.2 and 10.3.

10.2 Test information to be reported shall include the following when applicable:

10.2.1 Material and sample identification,

10.2.2 Specimen type (see Section 6),

10.2.3 Yield strength and the method used to determine yield strength (see 7.6),

10.2.4 Tensile strength (see 7.7), and

10.2.5 Elongation, including original gage length, percent-age increase, and method used to determine elongation (see 7.8).

10.3 Test information to be available on request shall include:

10.3.1 Specimen test section dimension(s) (see Section 6),

10.3.2 Equation used to calculate cross-sectional area of rectangular specimens taken from large-diameter tubular products (see 7.2.3),

10.3.3 Speed and method used to determine speed of testing (see 7.5),

10.3.4 Method used for rounding of test results (see 7.9),

10.3.5 Reasons for replacement specimens (see Section 8), and

10.3.6 Reasons for retests (see Section 9).

11. Precision and Bias

11.1 *Precision*—An interlaboratory test program⁵ gave the following values for coefficients of variation for the most commonly measured tensile properties:

	Coefficient of Variation, %		
	Tensile Strength	Yield Strength Offset, 0.2 %	Elongation Gage Length, 4 Diameter
CV % _r	0.9	1.4	2.8
CV % _R	1.3	2.3	5.4

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

11.1.1 The values shown are the averages from tests on six frequently tested metals, selected to include most of the normal

⁵ Supporting data can be found in Appendix X1 and additional data are available from ASTM Headquarters. Request RR:E28-1004 and E28-1006.

range for each property previously listed. When these materials are compared, a large difference in coefficient of variation is found. Therefore, the preceding values should not be used to judge whether the difference between duplicate tests of a specific material is larger than expected. The values are provided to allow potential users of these test methods to assess, in general terms, their usefulness for a proposed application.

11.2 *Bias*—The procedures in Test Methods B 557 for measuring tensile properties have no bias because these properties can be defined only in terms of a test method.

12. Keywords

12.1 elongation; strain; stress; tensile strength; tensile testing; yield strength

APPENDIX

(Nonmandatory Information)

X1. FACTORS AFFECTING TENSION TEST RESULTS

X1.1 The precision and bias of tension test strength and ductility measurements depend on strict adherence to the stated test procedure and are influenced by instrumental and material factors, specimen preparation, and measurement/testing errors.

X1.2 The consistency of agreement for repeated tests of the same material is dependent on the homogeneity of the material, and the repeatability of specimen preparation, test conditions, and measurements of the tension test parameters.

X1.3 Instrumental factors that can affect test results include: the stiffness, damping capacity, natural frequency, and mass of the tensile test machine, the accuracy of force indication and the use of forces within the verified range for the machine, rate of force application, alignment of the test specimen with the applied force, parallelism of the grips, grip pressure, nature of the force control used, appropriateness and calibration of extensometers used, and so forth.

X1.4 Material factors that can affect test results include: homogeneity of the test material, sampling scheme, and specimen preparation (surface finish, dimensional accuracy, fillets at the ends of the gage length, taper in the gage length, bent specimens, thread quality, and so forth).

X1.4.1 Test results for specimens with as-cast, as-rolled, as-forged, or other non-machined surface conditions can be affected by the nature of the surface (see Note 8).

X1.4.2 Test specimens taken from appendages to the part or component, such as prolongs or risers, or from separately produced castings (for example, keel blocks) may produce test results that are not representative of the part or component.

X1.4.3 Test specimen dimensions can influence test results. For cylindrical or rectangular specimens, changing the test specimen size generally has negligible effect on the yield and tensile strength but may influence elongation. Comparison of elongation values determined using different specimens require that the following ratio be controlled:

$$L_o/(A_o)^{1/2} \quad (X1.1)$$

where:

L_o = original gage length of specimen, and

A_o = original cross-sectional area of specimen.

X1.4.3.1 Specimens with smaller $L_o/(A_o)^{1/2}$ ratios generally give greater elongation values. This is the case for example, when the width or thickness of a rectangular tensile test specimen is increased.

X1.4.3.2 Holding the $L_o/(A_o)^{1/2}$ ratio constant minimizes, but does not necessarily eliminate differences. Depending on material and test conditions, increasing the size of the proportional specimen of Fig. 9 may be found to increase or decrease elongation values somewhat.

X1.4.4 Use of a taper in the gage length, up to the allowed 1 % limit, can result in lower elongation values. Reductions of as much as 15 % have been reported for a 1 % taper.

X1.4.5 Changes in the strain rate can effect the yield strength, tensile strength, and elongation values, especially for materials which are highly strain-rate sensitive. In general, yield strength and tensile strength will increase with increasing strain rate, although the effect on tensile strength is generally less pronounced. Elongation values generally decrease as the strain rate increases. Aluminum alloys at room temperature are not highly strain-rate sensitive: some exhibit a slightly higher yield strength with increasing strain rate while others show the opposite effect.

X1.4.6 Brittle materials require careful specimen preparation, high-quality surface finishes, large fillets at the ends of the gage length, oversize threaded grip sections, and cannot tolerate punch or scribe marks as gage length indicators.

X1.4.7 Flattening of tubular products to permit testing does alter the material properties, generally nonuniformly, in the flattened region which may affect test results.

X1.5 Measurement errors that can affect test results include: verification of the test force, extensometers, micrometers, dividers, and other measurement devices, alignment and zeroing of chart recording devices, and so forth.

X1.5.1 Measurement of the dimensions of as-cast, as-rolled, as-forged, and other test specimens with non-machined surfaces may be imprecise due to the irregularity of the surface flatness.

X1.5.2 If any portion of the fracture occurs outside of the middle of the gage length, or in a punch or scribe mark within the gage length, the elongation may not be representative of the

material. Wire specimens that break at or within the grips may not produce test results representative of the material.

X1.6 Because standard reference materials with certified tensile property values are not available, it is not possible to rigorously define the bias of tension tests. However, by the use of carefully designed and controlled interlaboratory studies, a reasonable definition of the precision of tension test results can be obtained.

X1.6.1 An interlaboratory test program⁵ was conducted where six specimens each, of six different materials were prepared and tested by each of six different laboratories. Tables X1.1-X1.3 present the precision statistics, as defined in Practice E 691, for: tensile strength, 0.2 % yield strength, and % elongation in 4D. In each table, the first column lists the six materials tested, the second column lists the average of the average results obtained by the laboratories ($\bar{X}$), the third and fifth columns list the repeatability standard deviation (s_r) and reproducibility standard deviation (s_R), the fourth and sixth columns list the coefficients of variation for these standard deviations ($s_r/\bar{X}$ and $s_R/\bar{X}$ as a percent), and the seventh and eighth columns list the 95 % repeatability limit (r) and reproducibility limit (R).

X1.6.2 The averages (below columns four and six in each table) of the coefficients of variation permit a relative comparison of the repeatability (within-laboratory precision) and reproducibility (between-laboratory precision) of the tension test parameters. This shows that the ductility measurement exhibits less repeatability and reproducibility than the strength measurements. The overall ranking from the least to the most repeatable and reproducible is: % elongation in 4D, 0.2 % offset yield strength, and tensile strength. Note that the rankings are in the same order for the repeatability and reproducibility average coefficients of variation and that the reproducibility (between-laboratory precision) is poorer than the repeatability (within-laboratory precision), as would be expected.

X1.6.3 No comments about bias can be made for the interlaboratory study due to the lack of certified test results for these specimens. However, examination of the test results showed that one laboratory consistently exhibited higher than average strength values and lower than average ductility values for most of the specimens. One other laboratory had consistently lower than average tensile strength results for all specimens.

TABLE X1.1 Precision Statistics—Tensile Strength, ksi

Material	$\bar{X}$	s_r	$s_r/\bar{X}, \%$	s_R	$s_R/\bar{X}, \%$	r	R
EC-H19	25.66	0.63	2.45	0.63	2.45	1.76	1.76
2024-T351	71.26	0.88	1.24	0.96	1.34	2.47	2.68
ASTM A105	86.57	0.60	0.69	1.27	1.47	1.68	3.55
AISI 316	100.75	0.39	0.39	1.22	1.21	1.09	3.39
Inconel 600	99.48	0.42	0.43	0.72	0.72	1.19	2.02
SAE 51410	181.73	0.46	0.25	1.14	0.63	1.29	3.20
		Averages:	0.91		1.30		

TABLE X1.2 Precision Statistics—0.2 % Yield Strength, ksi

Material	X	S_r	$S_r/X, \%$	S_R	$S_R/X, \%$	r	R
EC-H19	22.98	0.47	2.06	0.48	2.07	1.33	1.33
2024-T351	52.64	0.74	1.41	0.79	1.49	2.08	2.20
ASTM A105	58.36	0.83	1.42	1.44	2.47	2.31	4.03
AISI 316	69.78	0.95	1.36	2.83	4.06	2.63	7.93
Inconel 600	38.91	0.36	0.93	0.85	2.17	1.01	2.37
SAE 51410	140.33	1.29	0.92	2.30	1.64	3.60	6.45
Averages:			1.35		2.32		

TABLE X1.3 Precision Statistics—% Elongation in 4D

Material	X	S_r	$S_r/X, \%$	S_R	$S_R/X, \%$	r	R
EC-H19	17.42	0.64	3.69	0.92	5.30	1.80	2.59
2024-T351	19.76	0.58	2.94	1.58	7.99	1.65	4.43
ASTM A105	29.10	0.76	2.62	0.98	3.38	2.13	2.76
AISI 316	40.07	1.10	2.75	2.14	5.35	3.09	6.00
Inconel 600	44.28	0.66	1.50	1.54	3.48	1.86	4.31
SAE 51410	14.48	0.48	3.29	0.99	6.83	1.34	2.77
Averages:			2.80		5.39		

SUMMARY OF CHANGES

This section identifies the principal changes to this standard that have been incorporated since the last issue.

(1) References to several casting specifications were removed from paragraph 6.3.2 and Referenced Documents.

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