Standard Test Methods and Definitions for Mechanical Testing of Steel Products[1]

This standard is issued under the fixed designation A 370; 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[2] cover procedures and definitions for the mechanical testing of wrought and cast steels, stainless steels, and related alloys. The various mechanical tests herein described are used to determine properties required in the product specifications. Variations in testing methods are to be avoided, and standard methods of testing are to be followed to obtain reproducible and comparable results. In those cases in which the testing requirements for certain products are unique or at variance with these general procedures, the product specification testing requirements shall control.

1.2 The following mechanical tests are described:

	Sections
Tension	5 to 13
Bend	14
Hardness	15
Brinell	16
Rockwell	17
Portable	18
Impact	19 to 28
Keywords	29

1.3 Annexes covering details peculiar to certain products are appended to these test methods as follows:

	Annex
Bar Products	A1.1
Tubular Products	Annex A2
Fasteners	Annex A3
Round Wire Products	Annex A4
Significance of Notched-Bar Impact Testing	Annex A5
Converting Percentage Elongation of Round Specimens to Equivalents for Flat Specimens	Annex A6
Testing Multi-Wire Strand	Annex A7
Rounding of Test Data	Annex A8
Methods for Testing Steel Reinforcing Bars	Annex A9
Procedure for Use and Control of Heat-Cycle Simulation	Annex A10

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

1.5 When this document is referenced in a metric product specification, the yield and tensile values may be determined in inch-pound (ksi) units then converted into SI (MPa) units. The elongation determined in inch-pound gage lengths of 2 or 8 in. may be reported in SI unit gage lengths of 50 or 200 mm, respectively, as applicable. Conversely, when this document is referenced in an inch-pound product specification, the yield and tensile values may be determined in SI units then converted into inch-pound units. The elongation determined in SI unit gage lengths of 50 or 200 mm may be reported in inch-pound gage lengths of 2 or 8 in., respectively, as applicable.

1.6 Attention is directed to Practices A 880 and E 1595 when there may be a need for information on criteria for evaluation of testing laboratories.

1.7 *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:* [3]

A 703/A 703M Specification for Steel Castings, General Requirements, for Pressure-Containing Parts

A 781/A 781M Specification for Castings, Steel and Alloy, Common Requirements, for General Industrial Use

A 833 Practice for Indentation Hardness of Metallic Materials by Comparison Hardness Testers

A 880 Practice for Criteria for Use in Evaluation of Testing Laboratories and Organizations for Examination and Inspection of Steel, Stainless Steel, and Related Alloys[4]

E 4 Practices for Force Verification of Testing Machines

E 6 Terminology Relating to Methods of Mechanical Testing

E 8 Test Methods for Tension Testing of Metallic Materials

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

E 10 Test Method for Brinell Hardness of Metallic Materials

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[1] These test methods and definitions are under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel and Related Alloys and are the direct responsibility of Subcommittee A01.13 on Mechanical and Chemical Testing and Processing Methods of Steel Products and Processes.

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[2] For *ASME Boiler and Pressure Vessel Code* applications see related Specification SA-370 in Section II of that Code.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[4] Withdrawn.

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

E 18 Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials
E 23 Test Methods for Notched Bar Impact Testing of Metallic Materials
E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
E 83 Practice for Verification and Classification of Extensometer Systems
E 110 Test Method for Indentation Hardness of Metallic Materials by Portable Hardness Testers
E 190 Test Method for Guided Bend Test for Ductility of Welds
E 290 Test Methods for Bend Testing of Material for Ductility
E 1595 Practice for Evaluating the Performance of Mechanical Testing Laboratories[4]

2.2 *ASME Document:*[5]
ASME Boiler and Pressure Vessel Code, Section VIII, Division I, Part UG-8

3. General Precautions

3.1 Certain methods of fabrication, such as bending, forming, and welding, or operations involving heating, may affect the properties of the material under test. Therefore, the product specifications cover the stage of manufacture at which mechanical testing is to be performed. The properties shown by testing prior to fabrication may not necessarily be representative of the product after it has been completely fabricated.

3.2 Improper machining or preparation of test specimens may give erroneous results. Care should be exercised to assure good workmanship in machining. Improperly machined specimens should be discarded and other specimens substituted.

3.3 Flaws in the specimen may also affect results. If any test specimen develops flaws, the retest provision of the applicable product specification shall govern.

3.4 If any test specimen fails because of mechanical reasons such as failure of testing equipment or improper specimen preparation, it may be discarded and another specimen taken.

4. Orientation of Test Specimens

4.1 The terms "longitudinal test" and "transverse test" are used only in material specifications for wrought products and are not applicable to castings. When such reference is made to a test coupon or test specimen, the following definitions apply:

4.1.1 *Longitudinal Test*, unless specifically defined otherwise, signifies that the lengthwise axis of the specimen is parallel to the direction of the greatest extension of the steel during rolling or forging. The stress applied to a longitudinal tension test specimen is in the direction of the greatest extension, and the axis of the fold of a longitudinal bend test specimen is at right angles to the direction of greatest extension (Fig. 1, Fig. 2a, and 2b).

4.1.2 *Transverse Test*, unless specifically defined otherwise, signifies that the lengthwise axis of the specimen is at right angles to the direction of the greatest extension of the steel during rolling or forging. The stress applied to a transverse tension test specimen is at right angles to the greatest extension, and the axis of the fold of a transverse bend test specimen is parallel to the greatest extension (Fig. 1).

4.2 The terms "radial test" and "tangential test" are used in material specifications for some wrought circular products and are not applicable to castings. When such reference is made to a test coupon or test specimen, the following definitions apply:

4.2.1 *Radial Test*, unless specifically defined otherwise, signifies that the lengthwise axis of the specimen is perpendicular to the axis of the product and coincident with one of the radii of a circle drawn with a point on the axis of the product as a center (Fig. 2a).

4.2.2 *Tangential Test*, unless specifically defined otherwise, signifies that the lengthwise axis of the specimen is perpendicular to a plane containing the axis of the product and tangent to a circle drawn with a point on the axis of the product as a center (Fig. 2a, 2b, 2c, and 2d).

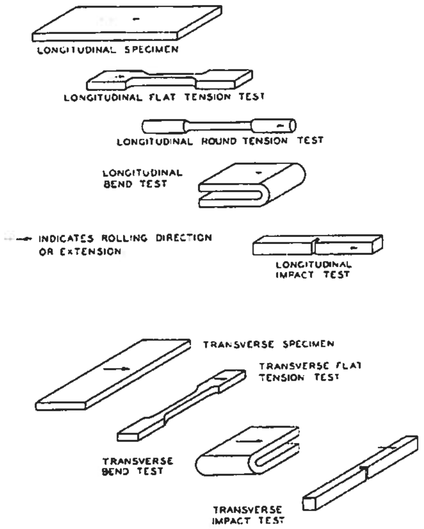


FIG. 1 The Relation of Test Coupons and Test Specimens to Rolling Direction or Extension (Applicable to General Wrought Products)

TENSION TEST

5. Description

5.1 The tension test related to the mechanical testing of steel products subjects a machined or full-section specimen of the material under examination to a measured load sufficient to cause rupture. The resulting properties sought are defined in Terminology E 6.

5.2 In general, the testing equipment and methods are given in Test Methods E 8. However, there are certain exceptions to Test Methods E 8 practices in the testing of steel, and these are covered in these test methods.

6. Terminology

6.1 For definitions of terms pertaining to tension testing, including tensile strength, yield point, yield strength, elongation, and reduction of area, reference should be made to Terminology E 6.

[5] Available from American Society of Mechanical Engineers (ASME), ASME International Headquarters, Three Park Ave., New York, NY 10016-5990.

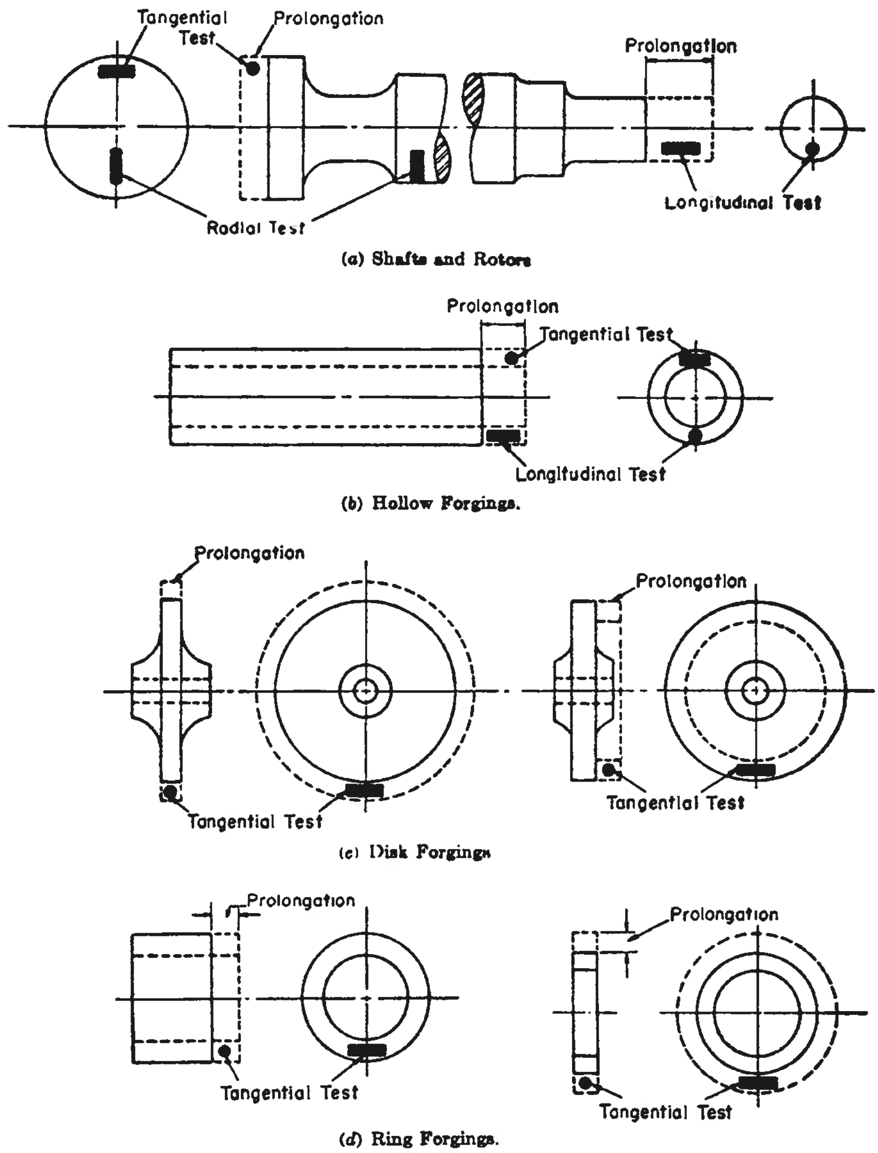


FIG. 2 Location of Longitudinal Tension Test Specimens in Rings Cut from Tubular Products

7. Testing Apparatus and Operations

7.1 *Loading Systems*—There are two general types of loading systems, mechanical (screw power) and hydraulic. These differ chiefly in the variability of the rate of load application. The older screw power machines are limited to a small number of fixed free running crosshead speeds. Some modern screw power machines, and all hydraulic machines permit stepless variation throughout the range of speeds.

7.2 The tension testing machine shall be maintained in good operating condition, used only in the proper loading range, and calibrated periodically in accordance with the latest revision of Practices E 4.

NOTE 1—Many machines are equipped with stress-strain recorders for autographic plotting of stress-strain curves. It should be noted that some recorders have a load measuring component entirely separate from the load indicator of the testing machine. Such recorders are calibrated separately.

7.3 *Loading*—It is the function of the gripping or holding device of the testing machine to transmit the load from the heads of the machine to the specimen under test. The essential requirement is that the load shall be transmitted axially. This implies that the centers of the action of the grips shall be in alignment, insofar as practicable, with the axis of the specimen at the beginning and during the test and that bending or twisting be held to a minimum. For specimens with a reduced section, gripping of the specimen shall be restricted to the grip section. In the case of certain sections tested in full size, nonaxial loading is unavoidable and in such cases shall be permissible.

7.4 *Speed of Testing*—The speed of testing shall not be greater than that at which load and strain readings can be made accurately. In production testing, speed of testing is commonly expressed: (*1*) in terms of free running crosshead speed (rate of movement of the crosshead of the testing machine when not under load), (*2*) in terms of rate of separation of the two heads of the testing machine under load, (*3*) in terms of rate of stressing the specimen, or (*4*) in terms of rate of straining the specimen. The following limitations on the speed of testing are recommended as adequate for most steel products:

NOTE 2—Tension tests using closed-loop machines (with feedback control of rate) should not be performed using load control, as this mode of testing will result in acceleration of the crosshead upon yielding and elevation of the measured yield strength.

7.4.1 Any convenient speed of testing may be used up to one half the specified yield point or yield strength. When this point is reached, the free-running rate of separation of the crossheads shall be adjusted so as not to exceed 1⁄16 in. per min per inch of reduced section, or the distance between the grips for test specimens not having reduced sections. This speed shall be maintained through the yield point or yield strength. In determining the tensile strength, the free-running rate of separation of the heads shall not exceed 1⁄2 in. per min per inch of reduced section, or the distance between the grips for test specimens not having reduced sections. In any event, the minimum speed of testing shall not be less than 1⁄10 the specified maximum rates for determining yield point or yield strength and tensile strength.

7.4.2 It shall be permissible to set the speed of the testing machine by adjusting the free running crosshead speed to the above specified values, inasmuch as the rate of separation of heads under load at these machine settings is less than the specified values of free running crosshead speed.

7.4.3 As an alternative, if the machine is equipped with a device to indicate the rate of loading, the speed of the machine from half the specified yield point or yield strength through the yield point or yield strength may be adjusted so that the rate of stressing does not exceed 100 000 psi (690 MPa)/min. However, the minimum rate of stressing shall not be less than 10 000 psi (70 MPa)/min.

8. Test Specimen Parameters

8.1 *Selection*—Test coupons shall be selected in accordance with the applicable product specifications.

8.1.1 *Wrought Steels*—Wrought steel products are usually tested in the longitudinal direction, but in some cases, where size permits and the service justifies it, testing is in the transverse, radial, or tangential directions (see Fig. 1 and Fig. 2).

8.1.2 *Forged Steels*—For open die forgings, the metal for tension testing is usually provided by allowing extensions or prolongations on one or both ends of the forgings, either on all or a representative number as provided by the applicable product specifications. Test specimens are normally taken at mid-radius. Certain product specifications permit the use of a representative bar or the destruction of a production part for test purposes. For ring or disk-like forgings test metal is provided by increasing the diameter, thickness, or length of the forging. Upset disk or ring forgings, which are worked or extended by forging in a direction perpendicular to the axis of the forging, usually have their principal extension along concentric circles and for such forgings tangential tension specimens are obtained from extra metal on the periphery or end of the forging. For some forgings, such as rotors, radial tension tests are required. In such cases the specimens are cut or trepanned from specified locations.

8.1.3 *Cast Steels*—Test coupons for castings from which tension test specimens are prepared shall be in accordance with the requirements of Specifications A 703/A 703M or A 781/A 781M, as applicable.

8.2 *Size and Tolerances*—Test specimens shall be the full thickness or section of material as-rolled, or may be machined to the form and dimensions shown in Figs. 3-6, inclusive. The selection of size and type of specimen is prescribed by the applicable product specification. Full section specimens shall be tested in 8-in. (200-mm) gage length unless otherwise specified in the product specification.

8.3 *Procurement of Test Specimens*—Specimens shall be sheared, blanked, sawed, trepanned, or oxygen-cut from portions of the material. They are usually machined so as to have a reduced cross section at mid-length in order to obtain uniform distribution of the stress over the cross section and to localize the zone of fracture. When test coupons are sheared, blanked, sawed, or oxygen-cut, care shall be taken to remove by machining all distorted, cold-worked, or heat-affected areas from the edges of the section used in evaluating the test.

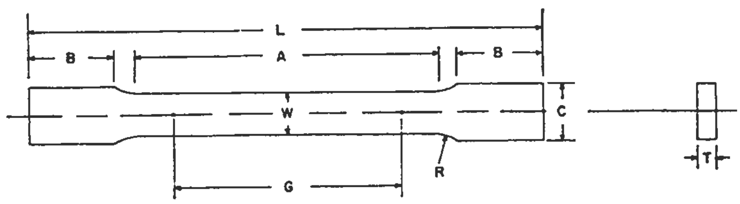
8.4 *Aging of Test Specimens*—Unless otherwise specified, it shall be permissible to age tension test specimens. The time-temperature cycle employed must be such that the effects of previous processing will not be materially changed. It may be accomplished by aging at room temperature 24 to 48 h, or in shorter time at moderately elevated temperatures by boiling in water, heating in oil or in an oven.

8.5 *Measurement of Dimensions of Test Specimens*:

8.5.1 *Standard Rectangular Tension Test Specimens*—These forms of specimens are shown in Fig. 3. To determine the cross-sectional area, the center width dimension shall be measured to the nearest 0.005 in. (0.13 mm) for the 8-in. (200-mm) gage length specimen and 0.001 in. (0.025 mm) for the 2-in. (50-mm) gage length specimen in Fig. 3. The center thickness dimension shall be measured to the nearest 0.001 in. for both specimens.

8.5.2 *Standard Round Tension Test Specimens*—These forms of specimens are shown in Fig. 4 and Fig. 5. To determine the cross-sectional area, the diameter shall be measured at the center of the gage length to the nearest 0.001 in. (0.025 mm) (see Table 1).

8.6 *General*—Test specimens shall be either substantially full size or machined, as prescribed in the product specifications for the material being tested.



DIMENSIONS

	Standard Specimens				Subsize Specimen	
	Plate-Type, 1½-in. Wide		Sheet-Type, ½-in. Wide		¼-in. Wide	
	in.	mm	in.	mm	in.	mm
G—Gage length (Notes 1 and 2)	8.00 ± 0.01	200 ± 0.25	2.000 ± 0.005	50.0 ± 0.10	1.000 ± 0.003	25.0 ± 0.08
W—Width (Notes 3, 5, and 6)	1½ + ⅛ − ¼	40 + 3 − 6	0.500 ± 0.010	12.5 ± 0.25	0.250 ± 0.002	6.25 ± 0.05
T—Thickness (Note 7)			Thickness of Material			
R—Radius of fillet, min (Note 4)	½	13	½	13	¼	6
L—Over-all length, min (Notes 2 and 8)	18	450	8	200	4	100
A—Length of reduced section, min	9	225	2¼	60	1¼	32
B—Length of grip section, min (Note 9)	3	75	2	50	1¼	32
C—Width of grip section, approximate (Notes 4, 10, and 11)	2	50	¾	20	⅜	10

NOTE 1—For the 1½-in. (40-mm) wide specimen, punch marks for measuring elongation after fracture shall be made on the flat or on the edge of the specimen and within the reduced section. Either a set of nine or more punch marks 1 in. (25 mm) apart, or one or more pairs of punch marks 8 in. (200 mm) apart may be used.

NOTE 2—For the ½-in. (12.5-mm) wide specimen, gage marks for measuring the elongation after fracture shall be made on the ½-inch (12.5-mm) face or on the edge of the specimen and within the reduced section. Either a set of three or more marks 1.0 in. (25 mm) apart or one or more pairs of marks 2 in. (50 mm) apart may be used.

NOTE 3—For the three sizes of specimens, the ends of the reduced section shall not differ in width by more than 0.004, 0.002 or 0.001 in. (0.10, 0.05 or 0.025 mm), respectively. Also, there may be a gradual decrease in width from the ends to the center, but the width at either end shall not be more than 0.015 in., 0.005 in., or 0.003 in. (0.40, 0.10 or 0.08 mm), respectively, larger than the width at the center.

NOTE 4—For each specimen type, the radii of all fillets shall be equal to each other with a tolerance of 0.05 in. (1.25 mm), 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. (2.5 mm).

NOTE 5—For each of the three sizes of 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 6—The specimen may be modified by making the sides parallel throughout the length of the specimen, the width and tolerances being the same as those specified above. When necessary a narrower specimen may be used, in which case the width should be as great as the width of the material being tested permits. If the width is 1½ in. (38 mm) or less, the sides may be parallel throughout the length of the specimen.

NOTE 7—The dimension *T* is the thickness of the test specimen as provided for in the applicable material specifications. Minimum nominal thickness of 1½-in. (40-mm) wide specimens shall be 3⁄16 in. (5 mm), except as permitted by the product specification. Maximum nominal thickness of ½-in. (12.5-mm) and ¼-in. (6-mm) wide specimens shall be ¾ in. (19 mm) and ¼ in. (6 mm), respectively.

NOTE 8—To aid in obtaining axial loading during testing of ¼-in. (6-mm) wide specimens, the overall length should be as the material will permit.

NOTE 9—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 ½-in. (13-mm) wide specimens is over ⅜ in. (10 mm), longer grips and correspondingly longer grip sections of the specimen may be necessary to prevent failure in the grip section.

NOTE 10—For standard sheet-type specimens and subsize specimens the ends of the specimen shall be symmetrical with the center line of the reduced section within 0.01 and 0.005 in. (0.25 and 0.13 mm), respectively. However, for steel if the ends of the ½-in. (12.5-mm) wide specimen are symmetrical within 0.05 in. (1.0 mm) a specimen may be considered satisfactory for all but referee testing.

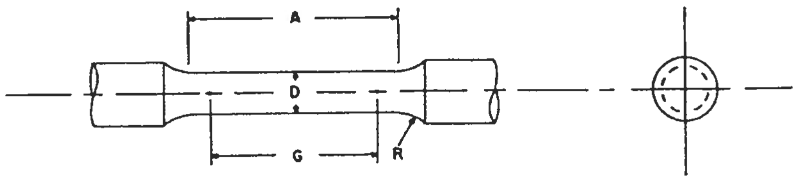
NOTE 11—For standard plate-type specimens the ends of the specimen shall be symmetrical with the center line of the reduced section within 0.25 in. (6.35 mm) except for referee testing in which case the ends of the specimen shall be symmetrical with the center line of the reduced section within 0.10 in. (2.5 mm).

FIG. 3 Rectangular Tension Test Specimens

8.6.1 Improperly prepared test specimens often cause unsatisfactory test results. It is important, therefore, that care be exercised in the preparation of specimens, particularly in the machining, to assure good workmanship.

8.6.2 It is desirable to have the cross-sectional area of the specimen smallest at the center of the gage length to ensure fracture within the gage length. This is provided for by the taper in the gage length permitted for each of the specimens described in the following sections.

8.6.3 For brittle materials it is desirable to have fillets of large radius at the ends of the gage length.



DIMENSIONS

	Standard Specimen		Small-Size Specimens Proportional to Standard							
Nominal Diameter	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm
	0.500	12.5	0.350	8.75	0.250	6.25	0.160	4.00	0.113	2.50
G—Gage length	2.00± 0.005	50.0 ± 0.10	1.400± 0.005	35.0 ± 0.10	1.000± 0.005	25.0 ± 0.10	0.640± 0.005	16.0 ± 0.10	0.450± 0.005	10.0 ± 0.10
D—Diameter (Note 1)	0.500± 0.010	12.5± 0.25	0.350± 0.007	8.75 ± 0.18	0.250± 0.005	6.25 ± 0.12	0.160± 0.003	4.00 ± 0.08	0.113± 0.002	2.50 ± 0.05
R—Radius of fillet, min	⅜	10	¼	6	3⁄16	5	5⁄32	4	3⁄32	2
A—Length of reduced section, min (Note 2)	2¼	60	1¾	45	1¼	32	¾	20	⅝	16

NOTE 1—The reduced section may have a gradual taper from the ends toward the center, with the ends not more than 1 percent 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. 9). If the ends are to be 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. 5 and Fig. 6, 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. (6.25-mm) 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—Five sizes of specimens often used have diameters of approximately 0.505, 0.357, 0.252, 0.160, and 0.113 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, 0.0200, and 0.0100 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, 50, and 100, respectively. (The metric equivalents of these fixed diameters do not result in correspondingly convenient cross sectional area and multiplying factors.)

FIG. 4 Standard 0.500-in. (12.5-mm) Round Tension Test Specimen with 2-in. (50-mm) Gage Length and Examples of Small-Size Specimens Proportional to the Standard Specimens

9. Plate-Type Specimen

9.1 The standard plate-type test specimen is shown in Fig. 3. This specimen is used for testing metallic materials in the form of plate, structural and bar-size shapes, and flat material having a nominal thickness of 3⁄16 in. (5 mm) or over. When product specifications so permit, other types of specimens may be used.

NOTE 3—When called for in the product specification, the 8-in. gage length specimen of Fig. 3 may be used for sheet and strip material.

10. Sheet-Type Specimen

10.1 The standard sheet-type test specimen is shown in Fig. 3. This specimen is used for testing metallic materials in the form of sheet, plate, flat wire, strip, band, and hoop ranging in nominal thickness from 0.005 to ¾ in. (0.13 to 19 mm). When product specifications so permit, other types of specimens may be used, as provided in Section 9 (see Note 3).

11. Round Specimens

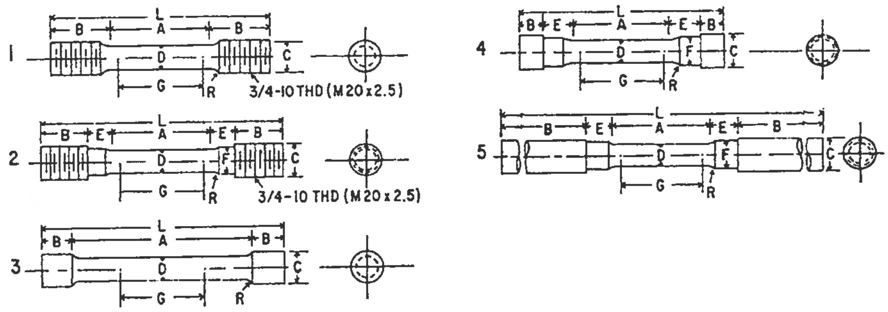
11.1 The standard 0.500-in. (12.5-mm) diameter round test specimen shown in Fig. 4 is used quite generally for testing metallic materials, both cast and wrought.

11.2 Fig. 4 also shows small size specimens proportional to the standard specimen. These may be used when it is necessary to test material from which the standard specimen or specimens shown in Fig. 3 cannot be prepared. Other sizes of small round specimens may be used. In any such small size specimen it is important that the gage length for measurement of elongation be four times the diameter of the specimen (see Note 4, Fig. 4).

11.3 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. 5 shows specimens with various types of ends that have given satisfactory results.

12. Gage Marks

12.1 The specimens shown in Figs. 3-6 shall be gage marked with a center punch, scribe marks, multiple device, or drawn with ink. The purpose of these gage marks is to determine the percent elongation. Punch marks shall be light, sharp, and accurately spaced. The localization of stress at the marks makes a hard specimen susceptible to starting fracture at the punch marks. The gage marks for measuring elongation after fracture shall be made on the flat or on the edge of the flat tension test specimen and within the parallel section; for the 8-in. gage length specimen, Fig. 3, one or more sets of 8-in. gage marks may be used, intermediate marks within the gage



DIMENSIONS

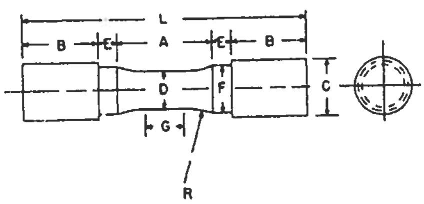
	Specimen 1		Specimen 2		Specimen 3		Specimen 4		Specimen 5	
	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm
G—Gage length	2.000± 0.005	50.0 ± 0.10	2.000± 0.005	50.0 ± 0.10	2.000± 0.005	50.0 ± 0.10	2.000± 0.005	50.0 ± 0.10	2.00± 0.005	50.0 ± 0.10
D—Diameter (Note 1)	0.500 ± 0.010	12.5± 0.25	0.500 ± 0.010	12.5± 0.25	0.500 ± 0.010	12.5± 0.25	0.500 ± 0.010	12.5± 0.25	0.500± 0.010	12.5 ± 0.25
R—Radius of fillet, min	⅜	10	⅜	10	1/16	2	⅜	10	⅜	10
A—Length of reduced section	2¼ , min	60, min	2¼ , min	60, min	4, approximately	100, approximately	2¼ , min	60, min	2¼ , min	60, min
L—Overall length, approximate	5	125	5½	140	5½	140	4¾	120	9½	240
B—Grip section (Note 2)	1⅜ , approximately	35, approximately	1, approximately	25, approximately	¾ , approximately	20, approximately	½ , approximately	13, approximately	3, min	75, min
C—Diameter of end section	¾	20	¾	20	23/32	18	⅞	22	¾	20
E—Length of shoulder and fillet section, approximate	...	...	⅝	16	...	...	¾	20	⅝	16
F—Diameter of shoulder	...	...	⅝	16	...	...	⅝	16	19/32	15

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. (0.10 mm) 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.

NOTE 3—The types of ends shown are applicable for the standard 0.500-in. round tension test specimen; similar types can be used for subsize specimens. The use of UNF series of threads (¾ by 16, ½ by 20, ⅜ by 24, and ¼ by 28) is suggested for high-strength brittle materials to avoid fracture in the thread portion.

FIG. 5 Suggested Types of Ends for Standard Round Tension Test Specimens



DIMENSIONS

	Specimen 1		Specimen 2		Specimen 3	
	in.	mm	in.	mm	in.	mm
G—Length of parallel	Shall be equal to or greater than diameter D					
D—Diameter	0.500 ± 0.010	12.5± 0.25	0.750 ± 0.015	20.0 ± 0.40	1.25 ± 0.025	30.0 ± 0.60
R—Radius of fillet, min	1	25	1	25	2	50
A—Length of reduced section, min	1¼	32	1½	38	2¼	60
L—Over-all length, min	3¾	95	4	100	6⅜	160
B—Grip section, approximate	1	25	1	25	1¾	45
C—Diameter of end section, approximate	¾	20	1⅛	30	1⅞	48
E—Length of shoulder, min	¼	6	¼	6	5/16	8
F—Diameter of shoulder	⅝ ± 1/64	16.0 ± 0.40	15/16 ± 1/64	24.0 ± 0.40	17/16 ± 1/64	36.5 ± 0.40

NOTE 1—The reduced section and shoulders (dimensions A, D, E, F, G, and R) shall be 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. Commonly the ends are threaded and have the dimensions B and C given above.

FIG. 6 Standard Tension Test Specimens for Cast Iron

TABLE 1 Multiplying Factors to Be Used for Various Diameters of Round Test Specimens

Standard Specimen			Small Size Specimens Proportional to Standard					
0.500 in. Round			0.350 in. Round			0.250 in. Round		
Actual Diameter, in.	Area, in.^{2}	Multiplying Factor	Actual Diameter, in.	Area, in.^{2}	Multiplying Factor	Actual Diameter, in.	Area, in.^{2}	Multiplying Factor
0.490	0.1886	5.30	0.343	0.0924	10.82	0.245	0.0471	21.21
0.491	0.1893	5.28	0.344	0.0929	10.76	0.246	0.0475	21.04
0.492	0.1901	5.26	0.345	0.0935	10.70	0.247	0.0479	20.87
0.493	0.1909	5.24	0.346	0.0940	10.64	0.248	0.0483	20.70
0.494	0.1917	5.22	0.347	0.0946	10.57	0.249	0.0487	20.54
0.495	0.1924	5.20	0.348	0.0951	10.51	0.250	0.0491	20.37
0.496	0.1932	5.18	0.349	0.0957	10.45	0.251	0.0495	20.21
							(0.05)^A	(20.0)^A
0.497	0.1940	5.15	0.350	0.0962	10.39	0.252	0.0499	20.05
							(0.05)^A	(20.0)^A
0.498	0.1948	5.13	0.351	0.0968	10.33	0.253	0.0503	19.89
							(0.05)^A	(20.0)^A
0.499	0.1956	5.11	0.352	0.0973	10.28	0.254	0.0507	19.74
0.500	0.1963	5.09	0.353	0.0979	10.22	0.255	0.0511	19.58
0.501	0.1971	5.07	0.354	0.0984	10.16	...	...	...
0.502	0.1979	5.05	0.355	0.0990	10.10	...	...	...
0.503	0.1987	5.03	0.356	0.0995	10.05	...	...	...
				(0.1)^A	(10.0)^A	...	...	...
0.504	0.1995	5.01	0.357	0.1001	9.99	...	...	...
	(0.2)^A	(5.0)^A		(0.1)^A	(10.0)^A	...	...	...
0.505	0.2003	4.99	...	...	...	...	...	...
	(0.2)^A	(5.0)^A						
0.506	0.2011	4.97	...	...	...	...	...	...
	(0.2)^A	(5.0)^A						
0.507	0.2019	4.95	...	...	...	...	...	...
0.508	0.2027	4.93	...	...	...	...	...	...
0.509	0.2035	4.91	...	...	...	...	...	...
0.510	0.2043	4.90	...	...	...	...	...	...

^{A} The values in parentheses may be used for ease in calculation of stresses, in pounds per square inch, as permitted in 5 of Fig. 4.

length being optional. Rectangular 2-in. gage length specimens, Fig. 3, and round specimens, Fig. 4, are gage marked with a double-pointed center punch or scribe marks. One or more sets of gage marks may be used; however, one set must be approximately centered in the reduced section. These same precautions shall be observed when the test specimen is full section.

13. Determination of Tensile Properties

13.1 *Yield Point*—Yield point is the first stress in a material, less than the maximum obtainable stress, at which an increase in strain occurs without an increase in stress. Yield point is intended for application only for materials that may exhibit the unique characteristic of showing an increase in strain without an increase in stress. The stress-strain diagram is characterized by a sharp knee or discontinuity. Determine yield point by one of the following methods:

13.1.1 *Drop of the Beam or Halt of the Pointer Method*—In this method, apply an increasing load to the specimen at a uniform rate. When a lever and poise machine is used, keep the beam in balance by running out the poise at approximately a steady rate. When the yield point of the material is reached, the increase of the load will stop, but run the poise a trifle beyond the balance position, and the beam of the machine will drop for a brief but appreciable interval of time. When a machine equipped with a load-indicating dial is used there is a halt or hesitation of the load-indicating pointer corresponding to the drop of the beam. Note the load at the "drop of the beam" or the "halt of the pointer" and record the corresponding stress as the yield point.

13.1.2 *Autographic Diagram Method*—When a sharp-kneed stress-strain diagram is obtained by an autographic recording device, take the stress corresponding to the top of the knee (Fig. 7), or the stress at which the curve drops as the yield point.

13.1.3 *Total Extension Under Load Method*—When testing material for yield point and the test specimens may not exhibit a well-defined disproportionate deformation that characterizes a yield point as measured by the drop of the beam, halt of the

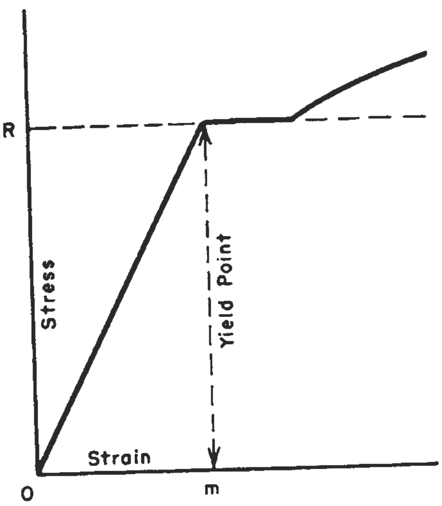


FIG. 7 Stress-Strain Diagram Showing Yield Point Corresponding with Top of Knee

pointer, or autographic diagram methods described in 13.1.1 and 13.1.2, a value equivalent to the yield point in its practical significance may be determined by the following method and may be recorded as yield point: Attach a Class C or better extensometer (Note 4 and Note 5) to the specimen. When the load producing a specified extension (Note 6) is reached record the stress corresponding to the load as the yield point (Fig. 8).

NOTE 4—Automatic devices are available that determine the load at the specified total extension without plotting a stress-strain curve. Such devices may be used if their accuracy has been demonstrated. Multiplying calipers and other such devices are acceptable for use provided their accuracy has been demonstrated as equivalent to a Class C extensometer.

NOTE 5—Reference should be made to Practice E 83.

NOTE 6—For steel with a yield point specified not over 80 000 psi (550 MPa), an appropriate value is 0.005 in./in. of gage length. For values above 80 000 psi, this method is not valid unless the limiting total extension is increased.

NOTE 7—The shape of the initial portion of an autographically determined stress-strain (or a load-elongation) curve may be influenced by numerous factors such as the seating of the specimen in the grips, the straightening of a specimen bent due to residual stresses, and the rapid loading permitted in 7.4.1. Generally, the aberrations in this portion of the curve should be ignored when fitting a modulus line, such as that used to determine the extension-under-load yield, to the curve.

13.2 *Yield Strength*—Yield strength is the stress at which a material exhibits a specified limiting deviation from the proportionality of stress to strain. The deviation is expressed in terms of strain, percent offset, total extension under load, etc. Determine yield strength by one of the following methods:

13.2.1 *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 with a distinct modulus characteristic of the material being tested may be drawn. Then on the stress-strain diagram (Fig. 9) lay off *Om* 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 curve corresponding to load *R*, which is the yield-strength load. In recording values of yield strength obtained by this method, the value of offset specified or used, or both, shall be stated in parentheses after the term yield strength, for example:

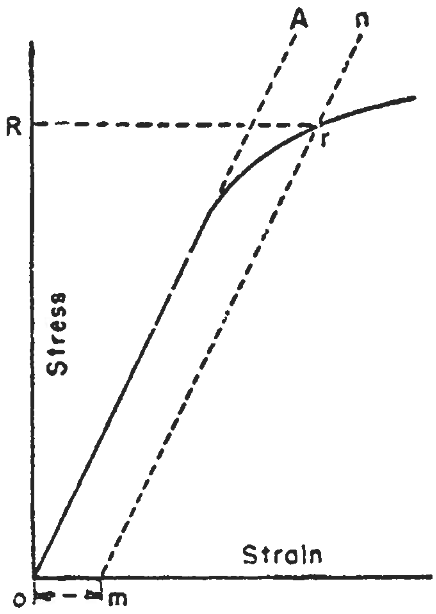


FIG. 9 Stress-Strain Diagram for Determination of Yield Strength by the Offset Method

$$\text{Yield strength (0.2 \% offset)} = 52\,000 \text{ psi (360 MPa)} \quad (1)$$

When the offset is 0.2 % or larger, the extensometer used shall qualify as a Class B2 device over a strain range of 0.05 to 1.0 %. If a smaller offset is specified, it may be necessary to specify a more accurate device (that is, a Class B1 device) or reduce the lower limit of the strain range (for example, to 0.01 %) or both. See also Note 9 for automatic devices.

NOTE 8—For stress-strain diagrams not containing a distinct modulus, such as for some cold-worked materials, it is recommended that the extension under load method be utilized. If the offset method is used for materials without a distinct modulus, a modulus value appropriate for the material being tested should be used: 30 000 000 psi (207 000 MPa) for carbon steel; 29 000 000 psi (200 000 MPa) for ferritic stainless steel; 28 000 000 psi (193 000 MPa) for austenitic stainless steel. For special alloys, the producer should be contacted to discuss appropriate modulus values.

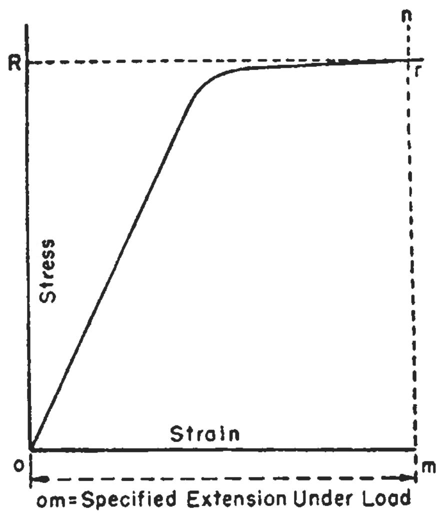


FIG. 8 Stress-Strain Diagram Showing Yield Point or Yield Strength by Extension Under Load Method

13.2.2 *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 (see Note 9 and Note 10) occurs will be known within satisfactory limits. The stress on the specimen, when this total strain is reached, is the value of the yield strength. In recording values of yield strength obtained by this method, the value of "extension" specified or used, or both, shall be stated in parentheses after the term yield strength, for example:

$$\text{Yield strength (0.5 \% } EUL) = 52\,000 \text{ psi (360 MPa)} \quad (2)$$

The total strain can be obtained satisfactorily by use of a Class B1 extensometer (Note 4, Note 5, and Note 7).

NOTE 9—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.

NOTE 10—The appropriate magnitude of the extension under load will obviously vary with the strength range of the particular steel under test. In general, the value of extension under load applicable to steel at any strength level may be determined from the sum of the proportional strain and the plastic strain expected at the specified yield strength. The following equation is used:

$$\text{Extension under load, in./in. of gage length} = (YS/E) + r \quad (3)$$

where:

YS = specified yield strength, psi or MPa,
E = modulus of elasticity, psi or MPa, and
r = limiting plastic strain, in./in.

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

13.4 *Elongation*:

13.4.1 Fit the ends of the fractured specimen together carefully and measure the distance between the gage marks to the nearest 0.01 in. (0.25 mm) for gage lengths of 2 in. and under, and to the nearest 0.5 % of the gage length for gage lengths over 2 in. A percentage scale reading to 0.5 % of the gage length may be used. The elongation is the increase in length of the gage length, expressed as a percentage of the original gage length. In recording elongation values, give both the percentage increase and the original gage length.

13.4.2 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 indicated, but if the elongation is less than the minimum requirements, discard the test and retest.

13.4.3 Automated tensile testing methods using extensometers allow for the measurement of elongation in a method described below. Elongation may be measured and reported either this way, or as in the method described above, fitting the broken ends together. Either result is valid.

13.4.4 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.

13.4.4.1 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. 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.

13.4.4.2 Percent elongation at fracture may be calculated directly from elongation at fracture data and be reported instead of percent elongation as calculated in 13.4.1. However, these two parameters are not interchangeable. Use of the elongation at fracture method generally provides more repeatable results.

13.5 *Reduction of Area*—Fit the ends of the fractured specimen together and measure the mean diameter or the width and thickness at the smallest cross section to the same accuracy as the original dimensions. The difference between the area thus found and the area of the original cross section expressed as a percentage of the original area is the reduction of area.

BEND TEST

14. Description

14.1 The bend test is one method for evaluating ductility, but it cannot be considered as a quantitative means of predicting service performance in bending operations. The severity of the bend test is primarily a function of the angle of bend of the inside diameter to which the specimen is bent, and of the cross section of the specimen. These conditions are varied according to location and orientation of the test specimen and the chemical composition, tensile properties, hardness, type, and quality of the steel specified. Test Method E 190 and Test Method E 290 may be consulted for methods of performing the test.

14.2 Unless otherwise specified, it shall be permissible to age bend test specimens. The time-temperature cycle employed must be such that the effects of previous processing will not be materially changed. It may be accomplished by aging at room temperature 24 to 48 h, or in shorter time at moderately elevated temperatures by boiling in water or by heating in oil or in an oven.

14.3 Bend the test specimen at room temperature to an inside diameter, as designated by the applicable product specifications, to the extent specified without major cracking on the outside of the bent portion. The speed of bending is ordinarily not an important factor.

HARDNESS TEST

15. General

15.1 A hardness test is a means of determining resistance to penetration and is occasionally employed to obtain a quick approximation of tensile strength. Table 2, Table 3, Table 4, and Table 5 are for the conversion of hardness measurements from one scale to another or to approximate tensile strength. These conversion values have been obtained from computer-generated curves and are presented to the nearest 0.1 point to permit accurate reproduction of those curves. Since all converted hardness values must be considered approximate, however, all converted Rockwell hardness numbers shall be rounded to the nearest whole number.

15.2 *Hardness Testing*:

15.2.1 If the product specification permits alternative hardness testing to determine conformance to a specified hardness

TABLE 2 Approximate Hardness Conversion Numbers for Nonaustenitic Steels[A] (Rockwell C to Other Hardness Numbers)

Rockwell C Scale, 150-kgf Load, Diamond Penetrator	Vickers Hardness Number	Brinell Hardness, 3000-kgf Load, 10-mm Ball	Knoop Hardness, 500-gf Load and Over	Rockwell A Scale, 60-kgf Load, Diamond Penetrator	Rockwell Superficial Hardness: 15N Scale, 15-kgf Load, Diamond Penetrator	Rockwell Superficial Hardness: 30N Scale 30-kgf Load, Diamond Penetrator	Rockwell Superficial Hardness: 45N Scale, 45-kgf Load, Diamond Penetrator	Approximate Tensile Strength, ksi (MPa)
68	940	...	920	85.6	93.2	84.4	75.4	...
67	900	...	895	85.0	92.9	83.6	74.2	...
66	865	...	870	84.5	92.5	82.8	73.3	...
65	832	739	846	83.9	92.2	81.9	72.0	...
64	800	722	822	83.4	91.8	81.1	71.0	...
63	772	706	799	82.8	91.4	80.1	69.9	...
62	746	688	776	82.3	91.1	79.3	68.8	...
61	720	670	754	81.8	90.7	78.4	67.7	...
60	697	654	732	81.2	90.2	77.5	66.6	...
59	674	634	710	80.7	89.8	76.6	65.5	351 (2420)
58	653	615	690	80.1	89.3	75.7	64.3	338 (2330)
57	633	595	670	79.6	88.9	74.8	63.2	325 (2240)
56	613	577	650	79.0	88.3	73.9	62.0	313 (2160)
55	595	560	630	78.5	87.9	73.0	60.9	301 (2070)
54	577	543	612	78.0	87.4	72.0	59.8	292 (2010)
53	560	525	594	77.4	86.9	71.2	58.6	283 (1 950)
52	544	512	576	76.8	86.4	70.2	57.4	273 (1 880)
51	528	496	558	76.3	85.9	69.4	56.1	264 (1 820)
50	513	482	542	75.9	85.5	68.5	55.0	255 (1 760)
49	498	468	526	75.2	85.0	67.6	53.8	246 (1 700)
48	484	455	510	74.7	84.5	66.7	52.5	238 (1 640)
47	471	442	495	74.1	83.9	65.8	51.4	229 (1 580)
46	458	432	480	73.6	83.5	64.8	50.3	221 (1 520)
45	446	421	466	73.1	83.0	64.0	49.0	215 (1 480)
44	434	409	452	72.5	82.5	63.1	47.8	208 (1 430)
43	423	400	438	72.0	82.0	62.2	46.7	201 (1 390)
42	412	390	426	71.5	81.5	61.3	45.5	194 (1 340)
41	402	381	414	70.9	80.9	60.4	44.3	188 (1 300)
40	392	371	402	70.4	80.4	59.5	43.1	182 (1 250)
39	382	362	391	69.9	79.9	58.6	41.9	177 (1 220)
38	372	353	380	69.4	79.4	57.7	40.8	171 (1 180)
37	363	344	370	68.9	78.8	56.8	39.6	166 (1 140)
36	354	336	360	68.4	78.3	55.9	38.4	161 (1 110)
35	345	327	351	67.9	77.7	55.0	37.2	156 (1 080)
34	336	319	342	67.4	77.2	54.2	36.1	152 (1 050)
33	327	311	334	66.8	76.6	53.3	34.9	149 (1 030)
32	318	301	326	66.3	76.1	52.1	33.7	146 (1 010)
31	310	294	318	65.8	75.6	51.3	32.5	141 (970)
30	302	286	311	65.3	75.0	50.4	31.3	138 (950)
29	294	279	304	64.6	74.5	49.5	30.1	135 (930)
28	286	271	297	64.3	73.9	48.6	28.9	131 (900)
27	279	264	290	63.8	73.3	47.7	27.8	128 (880)
26	272	258	284	63.3	72.8	46.8	26.7	125 (860)
25	266	253	278	62.8	72.2	45.9	25.5	123 (850)
24	260	247	272	62.4	71.6	45.0	24.3	119 (820)
23	254	243	266	62.0	71.0	44.0	23.1	117 (810)
22	248	237	261	61.5	70.5	43.2	22.0	115 (790)
21	243	231	256	61.0	69.9	42.3	20.7	112 (770)
20	238	226	251	60.5	69.4	41.5	19.6	110 (760)

[A] This table gives the approximate interrelationships of hardness values and approximate tensile strength of steels. It is possible that steels of various compositions and processing histories will deviate in hardness-tensile strength relationship from the data presented in this table. The data in this table should not be used for austenitic stainless steels, but have been shown to be applicable for ferritic and martensitic stainless steels. The data in this table should not be used to establish a relationship between hardness values and tensile strength of hard drawn wire. Where more precise conversions are required, they should be developed specially for each steel composition, heat treatment, and part.

TABLE 3 Approximate Hardness Conversion Numbers for Nonaustenitic Steels[A] (Rockwell B to Other Hardness Numbers)

Rockwell B Scale, 100-kgf Load 1/16-in. (1.588-mm) Ball	Vickers Hardness Number	Brinell Hardness, 3000-kgf Load, 10-mm Ball	Knoop Hardness, 500-gf Load and Over	Rockwell A Scale, 60-kgf Load, Diamond Penetrator	Rockwell F Scale, 60-kgf Load, 1/16-in. (1.588-mm) Ball	Rockwell Superficial Hardness: 15T Scale, 15-kgf Load, 1/16-in. (1.588-mm) Ball	Rockwell Superficial Hardness: 30T Scale, 30-kgf Load, 1/16-in. (1.588-mm) Ball	Rockwell Superficial Hardness: 45T Scale, 45-kgf Load, 1/16-in. (1.588-mm) Ball	Approximate Tensile Strength ksi (MPa)
100	240	240	251	61.5	...	93.1	83.1	72.9	116 (800)
99	234	234	246	60.9	...	92.8	82.5	71.9	114 (785)
98	228	228	241	60.2	...	92.5	81.8	70.9	109 (750)
97	222	222	236	59.5	...	92.1	81.1	69.9	104 (715)
96	216	216	231	58.9	...	91.8	80.4	68.9	102 (705)
95	210	210	226	58.3	...	91.5	79.8	67.9	100 (690)
94	205	205	221	57.6	...	91.2	79.1	66.9	98 (675)
93	200	200	216	57.0	...	90.8	78.4	65.9	94 (650)
92	195	195	211	56.4	...	90.5	77.8	64.8	92 (635)
91	190	190	206	55.8	...	90.2	77.1	63.8	90 (620)
90	185	185	201	55.2	...	89.9	76.4	62.8	89 (615)
89	180	180	196	54.6	...	89.5	75.8	61.8	88 (605)
88	176	176	192	54.0	...	89.2	75.1	60.8	86 (590)
87	172	172	188	53.4	...	88.9	74.4	59.8	84 (580)
86	169	169	184	52.8	...	88.6	73.8	58.8	83 (570)
85	165	165	180	52.3	...	88.2	73.1	57.8	82 (565)
84	162	162	176	51.7	...	87.9	72.4	56.8	81 (560)
83	159	159	173	51.1	...	87.6	71.8	55.8	80 (550)
82	156	156	170	50.6	...	87.3	71.1	54.8	77 (530)
81	153	153	167	50.0	...	86.9	70.4	53.8	73 (505)
80	150	150	164	49.5	...	86.6	69.7	52.8	72 (495)
79	147	147	161	48.9	...	86.3	69.1	51.8	70 (485)
78	144	144	158	48.4	...	86.0	68.4	50.8	69 (475)
77	141	141	155	47.9	...	85.6	67.7	49.8	68 (470)
76	139	139	152	47.3	...	85.3	67.1	48.8	67 (460)
75	137	137	150	46.8	99.6	85.0	66.4	47.8	66 (455)
74	135	135	147	46.3	99.1	84.7	65.7	46.8	65 (450)
73	132	132	145	45.8	98.5	84.3	65.1	45.8	64 (440)
72	130	130	143	45.3	98.0	84.0	64.4	44.8	63 (435)
71	127	127	141	44.8	97.4	83.7	63.7	43.8	62 (425)
70	125	125	139	44.3	96.8	83.4	63.1	42.8	61 (420)
69	123	123	137	43.8	96.2	83.0	62.4	41.8	60 (415)
68	121	121	135	43.3	95.6	82.7	61.7	40.8	59 (405)
67	119	119	133	42.8	95.1	82.4	61.0	39.8	58 (400)
66	117	117	131	42.3	94.5	82.1	60.4	38.7	57 (395)
65	116	116	129	41.8	93.9	81.8	59.7	37.7	56 (385)
64	114	114	127	41.4	93.4	81.4	59.0	36.7	...
63	112	112	125	40.9	92.8	81.1	58.4	35.7	...
62	110	110	124	40.4	92.2	80.8	57.7	34.7	...
61	108	108	122	40.0	91.7	80.5	57.0	33.7	...
60	107	107	120	39.5	91.1	80.1	56.4	32.7	...
59	106	106	118	39.0	90.5	79.8	55.7	31.7	...
58	104	104	117	38.6	90.0	79.5	55.0	30.7	...
57	103	103	115	38.1	89.4	79.2	54.4	29.7	...
56	101	101	114	37.7	88.8	78.8	53.7	28.7	...
55	100	100	112	37.2	88.2	78.5	53.0	27.7	...
54	...	...	111	36.8	87.7	78.2	52.4	26.7	...
53	...	...	110	36.3	87.1	77.9	51.7	25.7	...
52	...	...	109	35.9	86.5	77.5	51.0	24.7	...
51	...	...	108	35.5	86.0	77.2	50.3	23.7	...
50	...	...	107	35.0	85.4	76.9	49.7	22.7	...
49	...	...	106	34.6	84.8	76.6	49.0	21.7	...
48	...	...	105	34.1	84.3	76.2	48.3	20.7	...
47	...	...	104	33.7	83.7	75.9	47.7	19.7	...
46	...	...	103	33.3	83.1	75.6	47.0	18.7	...
45	...	...	102	32.9	82.6	75.3	46.3	17.7	...
44	...	...	101	32.4	82.0	74.9	45.7	16.7	...
43	...	...	100	32.0	81.4	74.6	45.0	15.7	...
42	...	...	99	31.6	80.8	74.3	44.3	14.7	...
41	...	...	98	31.2	80.3	74.0	43.7	13.6	...
40	...	...	97	30.7	79.7	73.6	43.0	12.6	...
39	...	...	96	30.3	79.1	73.3	42.3	11.6	...
38	...	...	95	29.9	78.6	73.0	41.6	10.6	...
37	...	...	94	29.5	78.0	72.7	41.0	9.6	...
36	...	...	93	29.1	77.4	72.3	40.3	8.6	...
35	...	...	92	28.7	76.9	72.0	39.6	7.6	...
34	...	...	91	28.2	76.3	71.7	39.0	6.6	...
33	...	...	90	27.8	75.7	71.4	38.3	5.6	...

TABLE 3 *Continued*

Rockwell B Scale, 100-kgf Load 1/16-in. (1.588-mm) Ball	Vickers Hardness Number	Brinell Hardness, 3000-kgf Load, 10-mm Ball	Knoop Hardness, 500-gf Load and Over	Rockwell A Scale, 60-kgf Load, Diamond Penetrator	Rockwell F Scale, 60-kgf Load, 1/16-in. (1.588-mm) Ball	Rockwell Superficial Hardness: 15T Scale, 15-kgf Load, 1/16-in. (1.588-mm) Ball	30T Scale, 30-kgf Load, 1/16-in. (1.588-mm) Ball	45T Scale, 45-kgf Load, 1/16-in. (1.588-mm) Ball	Approximate Tensile Strength ksi (MPa)
32	...	...	89	27.4	75.2	71.0	37.6	4.6	...
31	...	...	88	27.0	74.6	70.7	37.0	3.6	...
30	...	...	87	26.6	74.0	70.4	36.3	2.6	...

[A] This table gives the approximate interrelationships of hardness values and approximate tensile strength of steels. It is possible that steels of various compositions and processing histories will deviate in hardness-tensile strength relationship from the data presented in this table. The data in this table should not be used for austenitic stainless steels, but have been shown to be applicable for ferritic and martensitic stainless steels. The data in this table should not be used to establish a relationship between hardness values and tensile strength of hard drawn wire. Where more precise conversions are required, they should be developed specially for each steel composition, heat treatment, and part.

TABLE 4 Approximate Hardness Conversion Numbers for Austenitic Steels (Rockwell C to other Hardness Numbers)

Rockwell C Scale, 150-kgf Load, Diamond Penetrator	Rockwell A Scale, 60-kgf Load, Diamond Penetrator	Rockwell Superficial Hardness: 15N Scale, 15-kgf Load, Diamond Penetrator	30N Scale, 30-kgf Load, Diamond Penetrator	45N Scale, 45-kgf Load, Diamond Penetrator
48	74.4	84.1	66.2	52.1
47	73.9	83.6	65.3	50.9
46	73.4	83.1	64.5	49.8
45	72.9	82.6	63.6	48.7
44	72.4	82.1	62.7	47.5
43	71.9	81.6	61.8	46.4
42	71.4	81.0	61.0	45.2
41	70.9	80.5	60.1	44.1
40	70.4	80.0	59.2	43.0
39	69.9	79.5	58.4	41.8
38	69.3	79.0	57.5	40.7
37	68.8	78.5	56.6	39.6
36	68.3	78.0	55.7	38.4
35	67.8	77.5	54.9	37.3
34	67.3	77.0	54.0	36.1
33	66.8	76.5	53.1	35.0
32	66.3	75.9	52.3	33.9
31	65.8	75.4	51.4	32.7
30	65.3	74.9	50.5	31.6
29	64.8	74.4	49.6	30.4
28	64.3	73.9	48.8	29.3
27	63.8	73.4	47.9	28.2
26	63.3	72.9	47.0	27.0
25	62.8	72.4	46.2	25.9
24	62.3	71.9	45.3	24.8
23	61.8	71.3	44.4	23.6
22	61.3	70.8	43.5	22.5
21	60.8	70.3	42.7	21.3
20	60.3	69.8	41.8	20.2

requirement, the conversions listed in Table 2, Table 3, Table 4, and Table 5 shall be used.

15.2.2 When recording converted hardness numbers, the measured hardness and test scale shall be indicated in parentheses, for example: 353 HB (38 HRC). This means that a hardness value of 38 was obtained using the Rockwell C scale and converted to a Brinell hardness of 353.

16. Brinell Test

16.1 *Description*:

16.1.1 A specified load is applied to a flat surface of the specimen to be tested, through a hard ball of specified diameter. The average diameter of the indentation is used as a basis for calculation of the Brinell hardness number. The quotient of the applied load divided by the area of the surface of the indentation, which is assumed to be spherical, is termed the Brinell hardness number (HB) in accordance with the following equation:

$$HB = P/[(\pi D/2)(D - \sqrt{D^2 - d^2})] \quad (4)$$

where:

HB = Brinell hardness number,
P = applied load, kgf,
D = diameter of the steel ball, mm, and
d = average diameter of the indentation, mm.

NOTE 11—The Brinell hardness number is more conveniently secured from standard tables such as Table 6, which show numbers corresponding to the various indentation diameters, usually in increments of 0.05 mm.

NOTE 12—In Test Method E 10 the values are stated in S I units, whereas in this section kg/m units are used.

TABLE 5 Approximate Hardness Conversion Numbers for Austenitic Steels (Rockwell B to other Hardness Numbers)

Rockwell B Scale, 100-kgf Load, 1/16-in. (1.588-mm) Ball	Brinell Indentation Diameter, mm	Brinell Hardness, 3000-kgf Load, 10-mm Ball	Rockwell A Scale, 60-kgf Load, Diamond Penetrator	Rockwell Superficial Hardness		
				15T Scale, 15-kgf Load, 1/16-in. (1.588-mm) Ball	30T Scale, 30-kgf Load, 1/16-in. (1.588-mm) Ball	45T Scale, 45-kgf Load, 1/16-in. (1.588-mm) Ball
100	3.79	256	61.5	91.5	80.4	70.2
99	3.85	248	60.9	91.2	79.7	69.2
98	3.91	240	60.3	90.8	79.0	68.2
97	3.96	233	59.7	90.4	78.3	67.2
96	4.02	226	59.1	90.1	77.7	66.1
95	4.08	219	58.5	89.7	77.0	65.1
94	4.14	213	58.0	89.3	76.3	64.1
93	4.20	207	57.4	88.9	75.6	63.1
92	4.24	202	56.8	88.6	74.9	62.1
91	4.30	197	56.2	88.2	74.2	61.1
90	4.35	192	55.6	87.8	73.5	60.1
89	4.40	187	55.0	87.5	72.8	59.0
88	4.45	183	54.5	87.1	72.1	58.0
87	4.51	178	53.9	86.7	71.4	57.0
86	4.55	174	53.3	86.4	70.7	56.0
85	4.60	170	52.7	86.0	70.0	55.0
84	4.65	167	52.1	85.6	69.3	54.0
83	4.70	163	51.5	85.2	68.6	52.9
82	4.74	160	50.9	84.9	67.9	51.9
81	4.79	156	50.4	84.5	67.2	50.9
80	4.84	153	49.8	84.1	66.5	49.9

16.1.2 The standard Brinell test using a 10-mm ball employs a 3000-kgf load for hard materials and a 1500 or 500-kgf load for thin sections or soft materials (see Annex A2 on Steel Tubular Products). Other loads and different size indentors may be used when specified. In recording hardness values, the diameter of the ball and the load must be stated except when a 10-mm ball and 3000-kgf load are used.

16.1.3 A range of hardness can properly be specified only for quenched and tempered or normalized and tempered material. For annealed material a maximum figure only should be specified. For normalized material a minimum or a maximum hardness may be specified by agreement. In general, no hardness requirements should be applied to untreated material.

16.1.4 Brinell hardness may be required when tensile properties are not specified.

16.2 *Apparatus*—Equipment shall meet the following requirements:

16.2.1 *Testing Machine*— A Brinell hardness testing machine is acceptable for use over a loading range within which its load measuring device is accurate to ±1 %.

16.2.2 *Measuring Microscope*—The divisions of the micrometer scale of the microscope or other measuring devices used for the measurement of the diameter of the indentations shall be such as to permit the direct measurement of the diameter to 0.1 mm and the estimation of the diameter to 0.05 mm.

NOTE 13—This requirement applies to the construction of the microscope only and is not a requirement for measurement of the indentation, see 16.4.3.

16.2.3 *Standard Ball*— The standard ball for Brinell hardness testing is 10 mm (0.3937 in.) in diameter with a deviation from this value of not more than 0.005 mm (0.0004 in.) in any diameter. A ball suitable for use must not show a permanent change in diameter greater than 0.01 mm (0.0004 in.) when pressed with a force of 3000 kgf against the test specimen.

16.3 *Test Specimen*—Brinell hardness tests are made on prepared areas and sufficient metal must be removed from the surface to eliminate decarburized metal and other surface irregularities. The thickness of the piece tested must be such that no bulge or other marking showing the effect of the load appears on the side of the piece opposite the indentation.

16.4 *Procedure:*

16.4.1 It is essential that the applicable product specifications state clearly the position at which Brinell hardness indentations are to be made and the number of such indentations required. The distance of the center of the indentation from the edge of the specimen or edge of another indentation must be at least two and one-half times the diameter of the indentation.

16.4.2 Apply the load for a minimum of 15 s.

16.4.3 Measure two diameters of the indentation at right angles to the nearest 0.1 mm, estimate to the nearest 0.05 mm, and average to the nearest 0.05 mm. If the two diameters differ by more than 0.1 mm, discard the readings and make a new indentation.

TABLE 6 Brinell Hardness Numbers[A]
(Ball 10 mm in Diameter, Applied Loads of 500, 1500, and 3000 kgf)

Diameter of Indentation, mm	Brinell Hardness Number			Diameter of Indentation, mm	Brinell Hardness Number			Diameter of Indentation, mm	Brinell Hardness Number			Diameter of Indentation, mm	Brinell Hardness Number		
	500-kgf Load	1500-kgf Load	3000-kgf Load		500-kgf Load	1500-kgf Load	3000-kgf Load		500-kgf Load	1500-kgf Load	3000-kgf Load		500-kgf Load	1500-kgf Load	3000-kgf Load
2.00	158	473	945	2.60	92.6	278	555	3.20	60.5	182	363	3.80	42.4	127	255
2.01	156	468	936	2.61	91.8	276	551	3.21	60.1	180	361	3.81	42.2	127	253
2.02	154	463	926	2.62	91.1	273	547	3.22	59.8	179	359	3.82	42.0	126	252
2.03	153	459	917	2.63	90.4	271	543	3.23	59.4	178	356	3.83	41.7	125	250
2.04	151	454	908	2.64	89.7	269	538	3.24	59.0	177	354	3.84	41.5	125	249
2.05	150	450	899	2.65	89.0	267	534	3.25	58.6	176	352	3.85	41.3	124	248
2.06	148	445	890	2.66	88.4	265	530	3.26	58.3	175	350	3.86	41.1	123	246
2.07	147	441	882	2.67	87.7	263	526	3.27	57.9	174	347	3.87	40.9	123	245
2.08	146	437	873	2.68	87.0	261	522	3.28	57.5	173	345	3.88	40.6	122	244
2.09	144	432	865	2.69	86.4	259	518	3.29	57.2	172	343	3.89	40.4	121	242
2.10	143	428	856	2.70	85.7	257	514	3.30	56.8	170	341	3.90	40.2	121	241
2.11	141	424	848	2.71	85.1	255	510	3.31	56.5	169	339	3.91	40.0	120	240
2.12	140	420	840	2.72	84.4	253	507	3.32	56.1	168	337	3.92	39.8	119	239
2.13	139	416	832	2.73	83.8	251	503	3.33	55.8	167	335	3.93	39.6	119	237
2.14	137	412	824	2.74	83.2	250	499	3.34	55.4	166	333	3.94	39.4	118	236
2.15	136	408	817	2.75	82.6	248	495	3.35	55.1	165	331	3.95	39.1	117	235
2.16	135	404	809	2.76	81.9	246	492	3.36	54.8	164	329	3.96	38.9	117	234
2.17	134	401	802	2.77	81.3	244	488	3.37	54.4	163	326	3.97	38.7	116	232
2.18	132	397	794	2.78	80.8	242	485	3.38	54.1	162	325	3.98	38.5	116	231
2.19	131	393	787	2.79	80.2	240	481	3.39	53.8	161	323	3.99	38.3	115	230
2.20	130	390	780	2.80	79.6	239	477	3.40	53.4	160	321	4.00	38.1	114	229
2.21	129	386	772	2.81	79.0	237	474	3.41	53.1	159	319	4.01	37.9	114	228
2.22	128	383	765	2.82	78.4	235	471	3.42	52.8	158	317	4.02	37.7	113	226
2.23	126	379	758	2.83	77.9	234	467	3.43	52.5	157	315	4.03	37.5	113	225
2.24	125	376	752	2.84	77.3	232	464	344	52.2	156	313	4.04	37.3	112	224
2.25	124	372	745	2.85	76.8	230	461	3.45	51.8	156	311	4.05	37.1	111	223
2.26	123	369	738	2.86	76.2	229	457	3.46	51.5	155	309	4.06	37.0	111	222
2.27	122	366	732	2.87	75.7	227	454	3.47	51.2	154	307	4.07	36.8	110	221
2.28	121	363	725	2.88	75.1	225	451	3.48	50.9	153	306	4.08	36.6	110	219
2.29	120	359	719	2.89	74.6	224	448	3.49	50.6	152	304	4.09	36.4	109	218
2.30	119	356	712	2.90	74.1	222	444	3.50	50.3	151	302	4.10	36.2	109	217
2.31	118	353	706	2.91	73.6	221	441	3.51	50.0	150	300	4.11	36.0	108	216
2.32	117	350	700	2.92	73.0	219	438	3.52	49.7	149	298	4.12	35.8	108	215
2.33	116	347	694	2.93	72.5	218	435	3.53	49.4	148	297	4.13	35.7	107	214
2.34	115	344	688	2.94	72.0	216	432	3.54	49.2	147	295	4.14	35.5	106	213
2.35	114	341	682	2.95	71.5	215	429	3.55	48.9	147	293	4.15	35.3	106	212
2.36	113	338	676	2.96	71.0	213	426	3.56	48.6	146	292	4.16	35.1	105	211
2.37	112	335	670	2.97	70.5	212	423	3.57	48.3	145	290	4.17	34.9	105	210
2.38	111	332	665	2.98	70.1	210	420	3.58	48.0	144	288	4.18	34.8	104	209
2.39	110	330	659	2.99	69.6	209	417	3.59	47.7	143	286	4.19	34.6	104	208
2.40	109	327	653	3.00	69.1	207	415	3.60	47.5	142	285	4.20	34.4	103	207
2.41	108	324	648	3.01	68.6	206	412	3.61	47.2	142	283	4.21	34.2	103	205
2.42	107	322	643	3.02	68.2	205	409	3.62	46.9	141	282	4.22	34.1	102	204
2.43	106	319	637	3.03	67.7	203	406	3.63	46.7	140	280	4.23	33.9	102	203
2.44	105	316	632	3.04	67.3	202	404	3.64	46.4	139	278	4.24	33.7	101	202
2.45	104	313	627	3.05	66.8	200	401	3.65	46.1	138	277	4.25	33.6	101	201
2.46	104	311	621	3.06	66.4	199	398	3.66	45.9	138	275	4.26	33.4	100	200
2.47	103	308	616	3.07	65.9	198	395	3.67	45.6	137	274	4.27	33.2	99.7	199
2.48	102	306	611	3.08	65.5	196	393	3.68	45.4	136	272	4.28	33.1	99.2	198
2.49	101	303	606	3.09	65.0	195	390	3.69	45.1	135	271	4.29	32.9	98.8	198
2.50	100	301	601	3.10	64.6	194	388	3.70	44.9	135	269	4.30	32.8	98.3	197
2.51	99.4	298	597	3.11	64.2	193	385	3.71	44.6	134	268	4.31	32.6	97.8	196
2.52	98.6	296	592	3.12	63.8	191	383	3.72	44.4	133	266	4.32	32.4	97.3	195
2.53	97.8	294	587	3.13	63.3	190	380	3.73	44.1	132	265	4.33	32.3	96.8	194
2.54	97.1	291	582	3.14	62.9	189	378	3.74	43.9	132	263	4.34	32.1	96.4	193
2.55	96.3	289	578	3.15	62.5	188	375	3.75	43.6	131	262	4.35	32.0	95.9	192
2.56	95.5	287	573	3.16	62.1	186	373	3.76	43.4	130	260	4.36	31.8	95.5	191
2.57	94.8	284	569	3.17	61.7	185	370	3.77	43.1	129	259	4.37	31.7	95.0	190
2.58	94.0	282	564	3.18	61.3	184	368	3.78	42.9	129	257	4.38	31.5	94.5	189
2.59	93.3	280	560	3.19	60.9	183	366	3.79	42.7	128	256	4.39	31.4	94.1	188

TABLE 6 *Continued*

Diameter of Indenta-tion, mm	Brinell Hardness Number 500-kgf Load	Brinell Hardness Number 1500-kgf Load	Brinell Hardness Number 3000-kgf Load	Diameter of Indenta-tion, mm	Brinell Hardness Number 500-kgf Load	Brinell Hardness Number 1500-kgf Load	Brinell Hardness Number 3000-kgf Load	Diameter of Indenta-tion, mm	Brinell Hardness Number 500-kgf Load	Brinell Hardness Number 1500-kgf Load	Brinell Hardness Number 3000-kgf Load	Diameter of Indenta-tion, mm	Brinell Hardness Number 500-kgf Load	Brinell Hardness Number 1500-kgf Load	Brinell Hardness Number 3000-kgf Load
4.40	31.2	93.6	187	5.05	23.3	69.8	140	5.70	17.8	53.5	107	6.35	14.0	42.0	84.0
4.41	31.1	93.2	186	5.06	23.2	69.5	139	5.71	17.8	53.3	107	6.36	13.9	41.8	83.7
4.42	30.9	92.7	185	5.07	23.1	69.2	138	5.72	17.7	53.1	106	6.37	13.9	41.7	83.4
4.43	30.8	92.3	185	5.08	23.0	68.9	138	5.73	17.6	52.9	106	6.38	13.8	41.5	83.1
4.44	30.6	91.8	184	5.09	22.9	68.6	137	5.74	17.6	52.7	105	6.39	13.8	41.4	82.8
4.45	30.5	91.4	183	5.10	22.8	68.3	137	5.75	17.5	52.5	105	6.40	13.7	41.2	82.5
4.46	30.3	91.0	182	5.11	22.7	68.0	136	5.76	17.4	52.3	105	6.41	13.7	41.1	82.2
4.47	30.2	90.5	181	5.12	22.6	67.7	135	5.77	17.4	52.1	104	6.42	13.6	40.9	81.9
4.48	30.0	90.1	180	5.13	22.5	67.4	135	5.78	17.3	51.9	104	6.43	13.6	40.8	81.6
4.49	29.9	89.7	179	5.14	22.4	67.1	134	5.79	17.2	51.7	103	6.44	13.5	40.6	81.3
4.50	29.8	89.3	179	5.15	22.3	66.9	134	5.80	17.2	51.5	103	6.45	13.5	40.5	81.0
4.51	29.6	88.8	178	5.16	22.2	66.6	133	5.81	17.1	51.3	103	6.46	13.4	40.4	80.7
4.52	29.5	88.4	177	5.17	22.1	66.3	133	5.82	17.0	51.1	102	6.47	13.4	40.2	80.4
4.53	29.3	88.0	176	5.18	22.0	66.0	132	5.83	17.0	50.9	102	6.48	13.4	40.1	80.1
4.54	29.2	87.6	175	5.19	21.9	65.8	132	5.84	16.9	50.7	101	6.49	13.3	39.9	79.8
4.55	29.1	87.2	174	5.20	21.8	65.5	131	5.85	16.8	50.5	101	6.50	13.3	39.8	79.6
4.56	28.9	86.8	174	5.21	21.7	65.2	130	5.86	16.8	50.3	101	6.51	13.2	39.6	79.3
4.57	28.8	86.4	173	5.22	21.6	64.9	130	5.87	16.7	50.2	100	6.52	13.2	39.5	79.0
4.58	28.7	86.0	172	5.23	21.6	64.7	129	5.88	16.7	50.0	99.9	6.53	13.1	39.4	78.7
4.59	28.5	85.6	171	5.24	21.5	64.4	129	5.89	16.6	49.8	99.5	6.54	13.1	39.2	78.4
4.60	28.4	85.4	170	5.25	21.4	64.1	128	5.90	16.5	49.6	99.2	6.55	13.0	39.1	78.2
4.61	28.3	84.8	170	5.26	21.3	63.9	128	5.91	16.5	49.4	98.8	6.56	13.0	38.9	78.0
4.62	28.1	84.4	169	5.27	21.2	63.6	127	5.92	16.4	49.2	98.4	6.57	12.9	38.8	77.6
4.63	28.0	84.0	168	5.28	21.1	63.3	127	5.93	16.3	49.0	98.0	6.58	12.9	38.7	77.3
4.64	27.9	83.6	167	5.29	21.0	63.1	126	5.94	16.3	48.8	97.7	6.59	12.8	38.5	77.1
4.65	27.8	83.3	167	5.30	20.9	62.8	126	5.95	16.2	48.7	97.3	6.60	12.8	38.4	76.8
4.66	27.6	82.9	166	5.31	20.9	62.6	125	5.96	16.2	48.5	96.9	6.61	12.8	38.3	76.5
4.67	27.5	82.5	165	5.32	20.8	62.3	125	5.97	16.1	48.3	96.6	6.62	12.7	38.1	76.2
4.68	27.4	82.1	164	5.33	20.7	62.1	124	5.98	16.0	48.1	96.2	6.63	12.7	38.0	76.0
4.69	27.3	81.8	164	5.34	20.6	61.8	124	5.99	16.0	47.9	95.9	6.64	12.6	37.9	75.7
4.70	27.1	81.4	163	5.35	20.5	61.5	123	6.00	15.9	47.7	95.5	6.65	12.6	37.7	75.4
4.71	27.0	81.0	162	5.36	20.4	61.3	123	6.01	15.9	47.6	95.1	6.66	12.5	37.6	75.2
4.72	26.9	80.7	161	5.37	20.3	61.0	122	6.02	15.8	47.4	94.8	6.67	12.5	37.5	74.9
4.73	26.8	80.3	161	5.38	20.3	60.8	122	6.03	15.7	47.2	94.4	6.68	12.4	37.3	74.7
4.74	26.6	79.9	160	5.39	20.2	60.6	121	6.04	15.7	47.0	94.1	6.69	12.4	37.2	74.4
4.75	26.5	79.6	159	5.40	20.1	60.3	121	6.05	15.6	46.8	93.7	6.70	12.4	37.1	74.1
4.76	26.4	79.2	158	5.41	20.0	60.1	120	6.06	15.6	46.7	93.4	6.71	12.3	36.9	73.9
4.77	26.3	78.9	158	5.42	19.9	59.8	120	6.07	15.5	46.5	93.0	6.72	12.3	36.8	73.6
4.78	26.2	78.5	157	5.43	19.9	59.6	119	6.08	15.4	46.3	92.7	6.73	12.2	36.7	73.4
4.79	26.1	78.2	156	5.44	19.8	59.3	119	6.09	15.4	46.2	92.3	6.74	12.2	36.6	73.1
4.80	25.9	77.8	156	5.45	19.7	59.1	118	6.10	15.3	46.0	92.0	6.75	12.1	36.4	72.8
4.81	25.8	77.5	155	5.46	19.6	58.9	118	6.11	15.3	45.8	91.7	6.76	12.1	36.3	72.6
4.82	25.7	77.1	154	5.47	19.5	58.6	117	6.12	15.2	45.7	91.3	6.77	12.1	36.2	72.3
4.83	25.6	76.8	154	5.48	19.5	58.4	117	6.13	15.2	45.5	91.0	6.78	12.0	36.0	72.1
4.84	25.5	76.4	153	5.49	19.4	58.2	116	6.14	15.1	45.3	90.6	6.79	12.0	35.9	71.8
4.85	25.4	76.1	152	5.50	19.3	57.9	116	6.15	15.1	45.2	90.3	6.80	11.9	35.8	71.6
4.86	25.3	75.8	152	5.51	19.2	57.7	115	6.16	15.0	45.0	90.0	6.81	11.9	35.7	71.3
4.87	25.1	75.4	151	5.52	19.2	57.5	115	6.17	14.9	44.8	89.6	6.82	11.8	35.5	71.1
4.88	25.0	75.1	150	5.53	19.1	57.2	114	6.18	14.9	44.7	89.3	6.83	11.8	35.4	70.8
4.89	24.9	74.8	150	5.54	19.0	57.0	114	6.19	14.8	44.5	89.0	6.84	11.8	35.3	70.6
4.90	24.8	74.4	149	5.55	18.9	56.8	114	6.20	14.7	44.3	88.7	6.86	11.7	35.2	70.4
4.91	24.7	74.1	148	5.56	18.9	56.6	113	6.21	14.7	44.2	88.3	6.86	11.7	35.1	70.1
4.92	24.6	73.8	148	5.57	18.8	56.3	113	6.22	14.7	44.0	88.0	6.87	11.6	34.9	69.9
4.93	24.5	73.5	147	5.58	18.7	56.1	112	6.23	14.6	43.8	87.7	6.88	11.6	34.8	69.6
4.94	24.4	73.2	146	5.59	18.6	55.9	112	6.24	14.6	43.7	87.4	6.89	11.6	34.7	69.4
4.95	24.3	72.8	146	5.60	18.6	55.7	111	6.25	14.5	43.5	87.1	6.90	11.5	34.6	69.2
4.96	24.2	72.5	145	5.61	18.5	55.5	111	6.26	14.5	43.4	86.7	6.91	11.5	34.5	68.9
4.97	24.1	72.2	144	5.62	18.4	55.2	110	6.27	14.4	43.2	86.4	6.92	11.4	34.3	68.7
4.98	24.0	71.9	144	5.63	18.3	55.0	110	6.28	14.4	43.1	86.1	6.93	11.4	34.2	68.4
4.99	23.9	71.6	143	5.64	18.3	54.8	110	6.29	14.3	42.9	85.8	6.94	11.4	34.1	68.2
5.00	23.8	71.3	143	5.65	18.2	54.6	109	6.30	14.2	42.7	85.5	6.95	11.3	34.0	68.0
5.01	23.7	71.0	142	5.66	18.1	54.4	109	6.31	14.2	42.6	85.2	6.96	11.3	33.9	67.7
5.02	23.6	70.7	141	5.67	18.1	54.2	108	6.32	14.1	42.4	84.9	6.97	11.3	33.8	67.5
5.03	23.5	70.4	141	5.68	18.0	54.0	108	6.33	14.1	42.3	84.6	6.98	11.2	33.6	67.3
5.04	23.4	70.1	140	5.69	17.9	53.7	107	6.34	14.0	42.1	84.3	6.99	11.2	33.5	67.0

[A] Prepared by the Engineering Mechanics Section, Institute for Standards Technology.

16.4.4 Do not use a steel ball on steels having a hardness over 450 HB nor a carbide ball on steels having a hardness over 650 HB. The Brinell hardness test is not recommended for materials having a hardness over 650 HB.

16.4.4.1 If a ball is used in a test of a specimen which shows a Brinell hardness number greater than the limit for the ball as detailed in 16.4.4, the ball shall be either discarded and replaced with a new ball or remeasured to ensure conformance with the requirements of Test Method E 10.

16.5 *Detailed Procedure*—For detailed requirements of this test, reference shall be made to the latest revision of Test Method E 10.

17. Rockwell Test

17.1 *Description:*

17.1.1 In this test a hardness value is obtained by determining the depth of penetration of a diamond point or a steel ball into the specimen under certain arbitrarily fixed conditions. A minor load of 10 kgf is first applied which causes an initial penetration, sets the penetrator on the material and holds it in position. A major load which depends on the scale being used is applied increasing the depth of indentation. The major load is removed and, with the minor load still acting, the Rockwell number, which is proportional to the difference in penetration between the major and minor loads is determined; this is usually done by the machine and shows on a dial, digital display, printer, or other device. This is an arbitrary number which increases with increasing hardness. The scales most frequently used are as follows:

Scale Symbol	Penetrator	Major Load, kgf	Minor Load, kgf
B	1/16-in. steel ball	100	10
C	Diamond brale	150	10

17.1.2 Rockwell superficial hardness machines are used for the testing of very thin steel or thin surface layers. Loads of 15, 30, or 45 kgf are applied on a hardened steel ball or diamond penetrator, to cover the same range of hardness values as for the heavier loads. The superficial hardness scales are as follows:

Scale Symbol	Penetrator	Major Load, kgf	Minor Load, kgf
15T	1/16-in. steel ball	15	3
30T	1/16-in. steel ball	30	3
45T	1/16-in. steel ball	45	3
15N	Diamond brale	15	3
30N	Diamond brale	30	3
45N	Diamond brale	45	3

17.2 *Reporting Hardness*—In recording hardness values, the hardness number shall always precede the scale symbol, for example: 96 HRB, 40 HRC, 75 HR15N, or 77 HR30T.

17.3 *Test Blocks*—Machines should be checked to make certain they are in good order by means of standardized Rockwell test blocks.

17.4 *Detailed Procedure*—For detailed requirements of this test, reference shall be made to the latest revision of Test Methods E 18.

18. Portable Hardness Test

18.1 Although the use of the standard, stationary Brinell or Rockwell hardness tester is generally preferred, it is not always possible to perform the hardness test using such equipment due to the part size or location. In this event, hardness testing using portable equipment as described in Practice A 833 or Test Method E 110 shall be used.

CHARPY IMPACT TESTING

19. Summary

19.1 A Charpy V-notch impact test is a dynamic test in which a notched specimen is struck and broken by a single blow in a specially designed testing machine. The measured test values may be the energy absorbed, the percentage shear fracture, the lateral expansion opposite the notch, or a combination thereof.

19.2 Testing temperatures other than room (ambient) temperature often are specified in product or general requirement specifications (hereinafter referred to as the specification). Although the testing temperature is sometimes related to the expected service temperature, the two temperatures need not be identical.

20. Significance and Use

20.1 *Ductile vs. Brittle Behavior*—Body-centered-cubic or ferritic alloys exhibit a significant transition in behavior when impact tested over a range of temperatures. At temperatures above transition, impact specimens fracture by a ductile (usually microvoid coalescence) mechanism, absorbing relatively large amounts of energy. At lower temperatures, they fracture in a brittle (usually cleavage) manner absorbing less energy. Within the transition range, the fracture will generally be a mixture of areas of ductile fracture and brittle fracture.

20.2 The temperature range of the transition from one type of behavior to the other varies according to the material being tested. This transition behavior may be defined in various ways for specification purposes.

20.2.1 The specification may require a minimum test result for absorbed energy, fracture appearance, lateral expansion, or a combination thereof, at a specified test temperature.

20.2.2 The specification may require the determination of the transition temperature at which either the absorbed energy or fracture appearance attains a specified level when testing is performed over a range of temperatures.

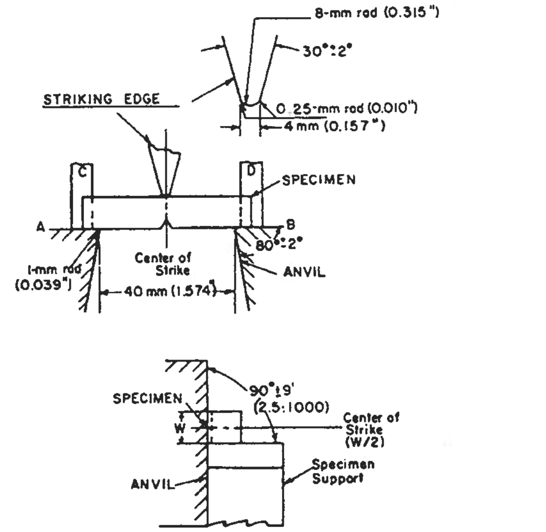
20.3 Further information on the significance of impact testing appears in Annex A5.

21. Apparatus

21.1 *Testing Machines:*

21.1.1 A Charpy impact machine is one in which a notched specimen is broken by a single blow of a freely swinging pendulum. The pendulum is released from a fixed height. Since the height to which the pendulum is raised prior to its swing, and the mass of the pendulum are known, the energy of the blow is predetermined. A means is provided to indicate the energy absorbed in breaking the specimen.

21.1.2 The other principal feature of the machine is a fixture (See Fig. 10) designed to support a test specimen as a simple



All dimensional tolerances shall be ±0.05 mm (0.002 in.) unless otherwise specified.

NOTE 1—A shall be parallel to B within 2:1000 and coplanar with B within 0.05 mm (0.002 in.).

NOTE 2—C shall be parallel to D within 20:1000 and coplanar with D within 0.125 mm (0.005 in.).

NOTE 3—Finish on unmarked parts shall be 4 µm (125 µin.).

FIG. 10 Charpy (Simple-Beam) Impact Test

beam at a precise location. The fixture is arranged so that the notched face of the specimen is vertical. The pendulum strikes the other vertical face directly opposite the notch. The dimensions of the specimen supports and striking edge shall conform to Fig. 10.

21.1.3 Charpy machines used for testing steel generally have capacities in the 220 to 300 ft·lbf (300 to 400 J) energy range. Sometimes machines of lesser capacity are used; however, the capacity of the machine should be substantially in excess of the absorbed energy of the specimens (see Test Methods E 23). The linear velocity at the point of impact should be in the range of 16 to 19 ft/s (4.9 to 5.8 m/s).

21.2 *Temperature Media*:

21.2.1 For testing at other than room temperature, it is necessary to condition the Charpy specimens in media at controlled temperatures.

21.2.2 Low temperature media usually are chilled fluids (such as water, ice plus water, dry ice plus organic solvents, or liquid nitrogen) or chilled gases.

21.2.3 Elevated temperature media are usually heated liquids such as mineral or silicone oils. Circulating air ovens may be used.

21.3 *Handling Equipment*—Tongs, especially adapted to fit the notch in the impact specimen, normally are used for removing the specimens from the medium and placing them on the anvil (refer to Test Methods E 23). In cases where the machine fixture does not provide for automatic centering of the test specimen, the tongs may be precision machined to provide centering.

22. Sampling and Number of Specimens

22.1 *Sampling*:

22.1.1 Test location and orientation should be addressed by the specifications. If not, for wrought products, the test location shall be the same as that for the tensile specimen and the orientation shall be longitudinal with the notch perpendicular to the major surface of the product being tested.

22.1.2 *Number of Specimens.*

22.1.2.1 A Charpy impact test consists of all specimens taken from a single test coupon or test location.

22.1.2.2 When the specification calls for a minimum average test result, three specimens shall be tested.

22.1.2.3 When the specification requires determination of a transition temperature, eight to twelve specimens are usually needed.

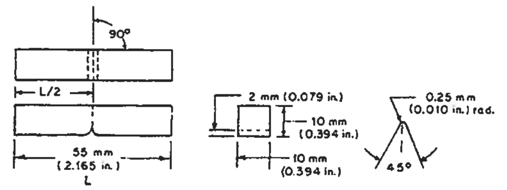
22.2 *Type and Size*:

22.2.1 Use a standard full size Charpy V-notch specimen (Type A) as shown in Fig. 11, except as allowed in 22.2.2.

22.2.2 *Subsized Specimens.*

22.2.2.1 For flat material less than 7⁄16 in. (11 mm) thick, or when the absorbed energy is expected to exceed 80 % of full scale, use standard subsize test specimens.

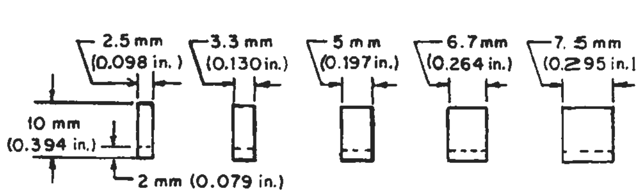
22.2.2.2 For tubular materials tested in the transverse direction, where the relationship between diameter and wall thickness does not permit a standard full size specimen, use standard



NOTE 1—Permissible variations shall be as follows:

Notch length to edge	90 ±2°
Adjacent sides shall be at	90° ± 10 min
Cross-section dimensions	±0.075 mm (±0.003 in.)
Length of specimen (L)	+ 0, − 2.5 mm (+ 0, − 0.100 in.)
Centering of notch (L/2)	±1 mm (±0.039 in.)
Angle of notch	±1°
Radius of notch	±0.025 mm (±0.001 in.)
Notch depth	±0.025 mm (±0.001 in.)
Finish requirements	2 µm (63 µin.) on notched surface and opposite face; 4 µm (125 µin.) on other two surfaces

(*a*) **Standard Full Size Specimen**



NOTE 2—On subsize specimens, all dimensions and tolerances of the standard specimen remain constant with the exception of the width, which varies as shown above and for which the tolerance shall be ±1 %.

(*b*) **Standard Subsize Specimens**

FIG. 11 Charpy (Simple Beam) Impact Test Specimens

subsize test specimens or standard size specimens containing outer diameter (OD) curvature as follows:

(1) Standard size specimens and subsize specimens may contain the original OD surface of the tubular product as shown in Fig. 12. All other dimensions shall comply with the requirements of Fig. 11.

NOTE 14—For materials with toughness levels in excess of about 50 ft-lbs. specimens containing the original OD surface may yield values in excess of those resulting from the use of conventional Charpy specimens.

22.2.2.3 If a standard full-size specimen cannot be prepared, the largest feasible standard subsize specimen shall be prepared. The specimens shall be machined so that the specimen does not include material nearer to the surface than 0.020 in. (0.5 mm).

22.2.2.4 Tolerances for standard subsize specimens are shown in Fig. 11. Standard subsize test specimen sizes are: 10 × 7.5 mm, 10 × 6.7 mm, 10 × 5 mm, 10 × 3.3 mm, and 10 × 2.5 mm.

22.2.2.5 Notch the narrow face of the standard subsize specimens so that the notch is perpendicular to the 10 mm wide face.

22.3 *Notch Preparation*—The machining of the notch is critical, as it has been demonstrated that extremely minor variations in notch radius and profile, or tool marks at the bottom of the notch may result in erratic test data. (See Annex A5).

23. Calibration

23.1 *Accuracy and Sensitivity*—Calibrate and adjust Charpy impact machines in accordance with the requirements of Test Methods E 23.

24. Conditioning—Temperature Control

24.1 When a specific test temperature is required by the specification or purchaser, control the temperature of the heating or cooling medium within ±2°F (1°C) because the effect of variations in temperature on Charpy test results can be very great.

NOTE 15—For some steels there may not be a need for this restricted temperature, for example, austenitic steels.

NOTE 16—Because the temperature of a testing laboratory often varies from 60 to 90°F (15 to 32°C) a test conducted at "room temperature" might be conducted at any temperature in this range.

25. Procedure

25.1 *Temperature*:

25.1.1 Condition the specimens to be broken by holding them in the medium at test temperature for at least 5 min in liquid media and 30 min in gaseous media.

25.1.2 Prior to each test, maintain the tongs for handling test specimens at the same temperature as the specimen so as not to affect the temperature at the notch.

25.2 *Positioning and Breaking Specimens*:

25.2.1 Carefully center the test specimen in the anvil and release the pendulum to break the specimen.

25.2.2 If the pendulum is not released within 5 s after removing the specimen from the conditioning medium, do not break the specimen. Return the specimen to the conditioning medium for the period required in 25.1.1.

25.3 *Recovering Specimens*—In the event that fracture appearance or lateral expansion must be determined, recover the matched pieces of each broken specimen before breaking the next specimen.

25.4 *Individual Test Values*:

25.4.1 *Impact energy*— Record the impact energy absorbed to the nearest ft·lbf (J).

25.4.2 *Fracture Appearance*:

25.4.2.1 Determine the percentage of shear fracture area by any of the following methods:

(1) Measure the length and width of the brittle portion of the fracture surface, as shown in Fig. 13 and determine the percent shear area from either Table 7 or Table 8 depending on the units of measurement.

(2) Compare the appearance of the fracture of the specimen with a fracture appearance chart as shown in Fig. 14.

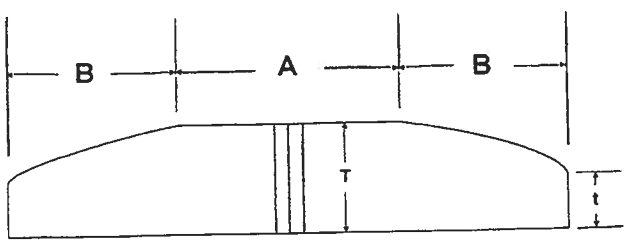
(3) Magnify the fracture surface and compare it to a precalibrated overlay chart or measure the percent shear fracture area by means of a planimeter.

(4) Photograph the fractured surface at a suitable magnification and measure the percent shear fracture area by means of a planimeter.

25.4.2.2 Determine the individual fracture appearance values to the nearest 5 % shear fracture and record the value.

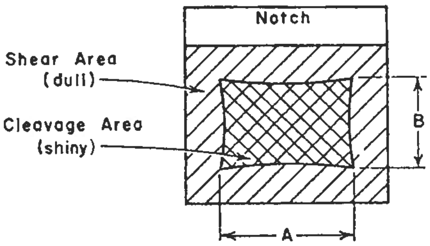
25.4.3 *Lateral Expansion*:

25.4.3.1 Lateral expansion is the increase in specimen width, measured in thousandths of an inch (mils), on the



Dimension	Description	Requirement
A	Machined Surface	28 mm Minimum
B	Original OD Surface	13 5 mm Maximum
T	Specimen Thickness	Figure 11
t	End Thickness	½ T Minimum

FIG. 12 Tubular Impact Specimen Containing Original OD Surface



NOTE 1—Measure average dimensions *A* and *B* to the nearest 0.02 in. or 0.5 mm.
NOTE 2—Determine the percent shear fracture using Table 7 or Table 8.

FIG. 13 Determination of Percent Shear Fracture

TABLE 7 Percent Shear for Measurements Made in Inches

NOTE 1—Since this table is set up for finite measurements or dimensions *A* and *B*, 100% shear is to be reported when either *A* or *B* is zero.

Dimension *B*, in.	Dimension *A*, in.																
	0.05	0.10	0.12	0.14	0.16	0.18	0.20	0.22	0.24	0.26	0.28	0.30	0.32	0.34	0.36	0.38	0.40
0.05	98	96	95	94	94	93	92	91	90	90	89	88	87	86	85	85	84
0.10	96	92	90	89	87	85	84	82	81	79	77	76	74	73	71	69	68
0.12	95	90	88	86	85	83	81	79	77	75	73	71	69	67	65	63	61
0.14	94	89	86	84	82	80	77	75	73	71	68	66	64	62	59	57	55
0.16	94	87	85	82	79	77	74	72	69	67	64	61	59	56	53	51	48
0.18	93	85	83	80	77	74	72	68	65	62	59	56	54	51	48	45	42
0.20	92	84	81	77	74	72	68	65	61	58	55	52	48	45	42	39	36
0.22	91	82	79	75	72	68	65	61	57	54	50	47	43	40	36	33	29
0.24	90	81	77	73	69	65	61	57	54	50	46	42	38	34	30	27	23
0.26	90	79	75	71	67	62	58	54	50	46	41	37	33	29	25	20	16
0.28	89	77	73	68	64	59	55	50	46	41	37	32	28	23	18	14	10
0.30	88	76	71	66	61	56	52	47	42	37	32	27	23	18	13	9	3
0.31	88	75	70	65	60	55	50	45	40	35	30	25	20	18	10	5	0

TABLE 8 Percent Shear for Measurements Made in Millimetres

NOTE 1—Since this table is set up for finite measurements or dimensions *A* and *B*, 100% shear is to be reported when either *A* or *B* is zero.

Dimension *B*, mm	Dimension *A*, mm																		
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10
1.0	99	98	98	97	96	96	95	94	94	93	92	92	91	91	90	89	89	88	88
1.5	98	97	96	95	94	93	92	92	91	90	89	88	87	86	85	84	83	82	81
2.0	98	96	95	94	92	91	90	89	88	86	85	84	82	81	80	79	77	76	75
2.5	97	95	94	92	91	89	88	86	84	83	81	80	78	77	75	73	72	70	69
3.0	96	94	92	91	89	87	85	83	81	79	77	76	74	72	70	68	66	64	62
3.5	96	93	91	89	87	85	82	80	78	76	74	72	69	67	65	63	61	58	56
4.0	95	92	90	88	85	82	80	77	75	72	70	67	65	62	60	57	55	52	50
4.5	94	92	89	86	83	80	77	75	72	69	66	63	61	58	55	52	49	46	44
5.0	94	91	88	85	81	78	75	72	69	66	62	59	56	53	50	47	44	41	37
5.5	93	90	86	83	79	76	72	69	66	62	59	55	52	48	45	42	38	35	31
6.0	92	89	85	81	77	74	70	66	62	59	55	51	47	44	40	36	33	29	25
6.5	92	88	84	80	76	72	67	63	59	55	51	47	43	39	35	31	27	23	19
7.0	91	87	82	78	74	69	65	61	56	52	47	43	39	34	30	26	21	17	12
7.5	91	86	81	77	72	67	62	58	53	48	44	39	34	30	25	20	16	11	6
8.0	90	85	80	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0

compression side, opposite the notch of the fractured Charpy V-notch specimen as shown in Fig. 15.

25.4.3.2 Examine each specimen half to ascertain that the protrusions have not been damaged by contacting the anvil, machine mounting surface, and so forth. Discard such samples since they may cause erroneous readings.

25.4.3.3 Check the sides of the specimens perpendicular to the notch to ensure that no burrs were formed on the sides during impact testing. If burrs exist, remove them carefully by rubbing on emery cloth or similar abrasive surface, making sure that the protrusions being measured are not rubbed during the removal of the burr.

25.4.3.4 Measure the amount of expansion on each side of each half relative to the plane defined by the undeformed portion of the side of the specimen using a gage similar to that shown in Fig. 16 and Fig. 17.

25.4.3.5 Since the fracture path seldom bisects the point of maximum expansion on both sides of a specimen, the sum of the larger values measured for each side is the value of the test. Arrange the halves of one specimen so that compression sides

FIG. 14 Fracture Appearance Charts and Percent Shear Fracture Comparator

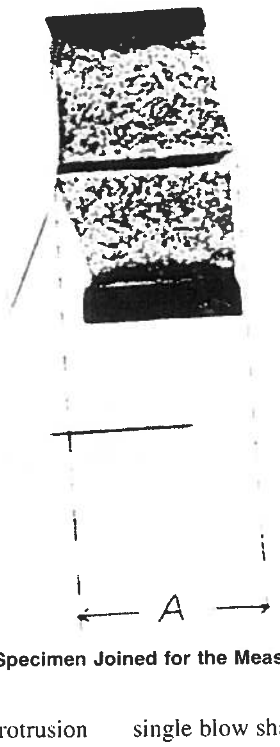


FIG. 15 Halves of Broken Charpy V-Notch Impact Specimen Joined for the Measurement of Lateral Expansion, Dimension A

are facing each other. Using the gage, measure the protrusion on each half specimen, ensuring that the same side of the specimen is measured. Measure the two broken halves individually. Repeat the procedure to measure the protrusions on the opposite side of the specimen halves. The larger of the two values for each side is the expansion of that side of the specimen.

25.4.3.6 Measure the individual lateral expansion values to the nearest mil (0.025 mm) and record the values.

25.4.3.7 With the exception described as follows, any specimen that does not separate into two pieces when struck by a single blow shall be reported as unbroken. If the specimen can be separated by force applied by bare hands, the specimen may be considered as having been separated by the blow.

26. Interpretation of Test Result

26.1 When the acceptance criterion of any impact test is specified to be a minimum average value at a given temperature, the test result shall be the average (arithmetic mean) of the individual test values of three specimens from one test location.

26.1.1 When a minimum average test result is specified:

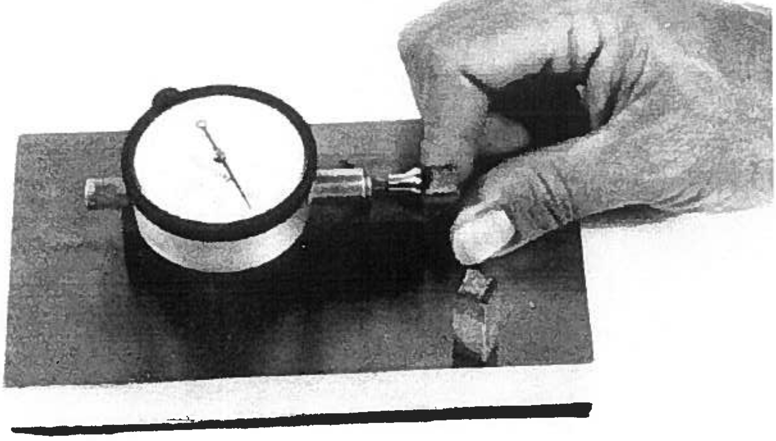
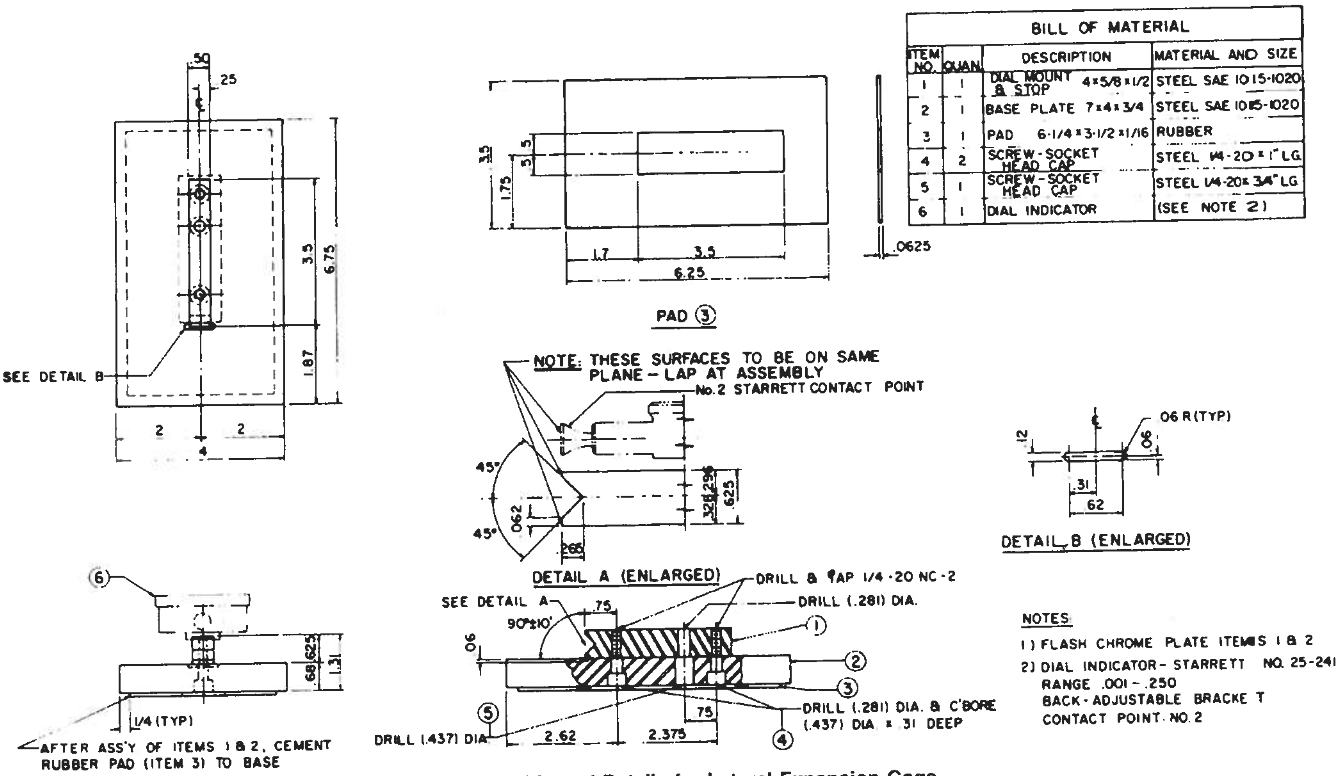


FIG. 16 Lateral Expansion Gage for Charpy Impact Specimens



BILL OF MATERIAL

ITEM NO.	QUAN.	DESCRIPTION	MATERIAL AND SIZE
1	1	DIAL MOUNT & STOP 4×5/8×1/2	STEEL SAE 1015-1020
2	1	BASE PLATE 7×4×3/4	STEEL SAE 1015-1020
3	1	PAD 6-1/4×3-1/2×1/16	RUBBER
4	2	SCREW - SOCKET HEAD CAP	STEEL 1/4-20×1" LG.
5	1	SCREW - SOCKET HEAD CAP	STEEL 1/4-20×3/4" LG
6	1	DIAL INDICATOR	(SEE NOTE 2)

FIG. 17 Assembly and Details for Lateral Expansion Gage

26.1.1.1 The test result is acceptable when all of the below are met:

(1) The test result equals or exceeds the specified minimum average (given in the specification),

(2) The individual test value for not more than one specimen measures less than the specified minimum average, and

(3) The individual test value for any specimen measures not less than two-thirds of the specified minimum average.

26.1.1.2 If the acceptance requirements of 26.1.1.1 are not met, perform one retest of three additional specimens from the same test location. Each individual test value of the retested specimens shall be equal to or greater than the specified minimum average value.

26.2 *Test Specifying a Minimum Transition Temperature*:

26.2.1 *Definition of Transition Temperature*—For specification purposes, the transition temperature is the temperature at which the designated material test value equals or exceeds a specified minimum test value.

26.2.2 *Determination of Transition Temperature*:

26.2.2.1 Break one specimen at each of a series of temperatures above and below the anticipated transition temperature using the procedures in Section 25. Record each test temperature to the nearest 1°F (0.5°C).

26.2.2.2 Plot the individual test results (ft·lbf or percent shear) as the ordinate versus the corresponding test temperature as the abscissa and construct a best-fit curve through the plotted data points.

26.2.2.3 If transition temperature is specified as the temperature at which a test value is achieved, determine the temperature at which the plotted curve intersects the specified test value by graphical interpolation (extrapolation is not permitted). Record this transition temperature to the nearest 5°F (3°C). If the tabulated test results clearly indicate a transition temperature lower than specified, it is not necessary to plot the data. Report the lowest test temperature for which test value exceeds the specified value.

26.2.2.4 Accept the test result if the determined transition temperature is equal to or lower than the specified value.

26.2.2.5 If the determined transition temperature is higher than the specified value, but not more than 20°F (12°C) higher than the specified value, test sufficient samples in accordance with Section 25 to plot two additional curves. Accept the test results if the temperatures determined from both additional tests are equal to or lower than the specified value.

26.3 When subsize specimens are permitted or necessary, or both, modify the specified test requirement according to Table 9 or test temperature according to ASME Boiler and Pressure Vessel Code, Table UG-84.2, or both. Greater energies or lower test temperatures may be agreed upon by purchaser and supplier.

27. Records

27.1 The test record should contain the following information as appropriate:

27.1.1 Full description of material tested (that is, specification number, grade, class or type, size, heat number).

27.1.2 Specimen orientation with respect to the material axis.

27.1.3 Specimen size.

27.1.4 Test temperature and individual test value for each specimen broken, including initial tests and retests.

27.1.5 Test results.

27.1.6 Transition temperature and criterion for its determination, including initial tests and retests.

28. Report

28.1 The specification should designate the information to be reported.

29. Keywords

29.1 bend test; Brinell hardness; Charpy impact test; elongation; FATT (Fracture Appearance Transition Temperature); hardness test; portable hardness; reduction of area; Rockwell hardness; tensile strength; tension test; yield strength

TABLE 9 Charpy V-Notch Test Acceptance Criteria for Various Sub-Size Specimens

Full Size, 10 by 10 mm		¾ Size, 10 by 7.5 mm		⅔ Size, 10 by 6.7 mm		½ Size, 10 by 5 mm		⅓ Size, 10 by 3.3 mm		¼ Size, 10 by 2.5 mm	
ft·lbf	[J]	ft·lbf	[J]	ft·lbf	[J]	ft·lbf	[J]	ft·lbf	[J]	ft·lbf	[J]
40	[54]	30	[41]	27	[37]	20	[27]	13	[18]	10	[14]
35	[48]	26	[35]	23	[31]	18	[24]	12	[16]	9	[12]
30	[41]	22	[30]	20	[27]	15	[20]	10	[14]	8	[11]
25	[34]	19	[26]	17	[23]	12	[16]	8	[11]	6	[8]
20	(27]	15	[20]	13	[18]	10	[14]	7	[10]	5	[7]
16	[22]	12	[16]	11	[15]	8	[11]	5	[7]	4	[5]
15	[20]	11	[15]	10	[14]	8	[11]	5	[7]	4	[5]
13	[18]	10	[14]	9	[12]	6	[8]	4	[5]	3	[4]
12	[16]	9	[12]	8	[11]	6	[8]	4	[5]	3	[4]
10	[14]	8	[11]	7	[10]	5	[7]	3	[4]	2	[3]
7	[10]	5	[7]	5	[7]	4	[5]	2	[3]	2	[3]

ANNEXES

(Mandatory Information)

A1. STEEL BAR PRODUCTS

A1.1 Scope

A1.1.1 This supplement delineates only those details which are peculiar to hot-rolled and cold-finished steel bars and are not covered in the general section of these test methods.

A1.2 Orientation of Test Specimens

A1.2.1 Carbon and alloy steel bars and bar-size shapes, due to their relatively small cross-sectional dimensions, are customarily tested in the longitudinal direction. In special cases where size permits and the fabrication or service of a part justifies testing in a transverse direction, the selection and location of test or tests are a matter of agreement between the manufacturer and the purchaser.

A1.3 Tension Test

A1.3.1 *Carbon Steel Bars*—Carbon steel bars are not commonly specified to tensile requirements in the as-rolled condition for sizes of rounds, squares, hexagons, and octagons under ½ in. (13 mm) in diameter or distance between parallel faces nor for other bar-size sections, other than flats, less than 1 $in.^2$ (645 mm^2) in cross-sectional area.

A1.3.2 *Alloy Steel Bars*—Alloy steel bars are usually not tested in the as-rolled condition.

A1.3.3 When tension tests are specified, the practice for selecting test specimens for hot-rolled and cold-finished steel bars of various sizes shall be in accordance with Table A1.1, unless otherwise specified in the product specification.

A1.4 Bend Test

A1.4.1 When bend tests are specified, the recommended practice for hot-rolled and cold-finished steel bars shall be in accordance with Table A1.2.

A1.5 Hardness Test

A1.5.1 *Hardness Tests on Bar Products*—flats, rounds, squares, hexagons and octagons—is conducted on the surface after a minimum removal of 0.015 in. to provide for accurate hardness penetration.

TABLE A1.1 Practices for Selecting Tension Test Specimens for Steel Bar Products

NOTE 1—For bar sections where it is difficult to determine the cross-sectional area by simple measurement, the area in square inches may be calculated by dividing the weight per linear inch of specimen in pounds by 0.2833 (weight of 1 in.^{3} of steel) or by dividing the weight per linear foot of specimen by 3.4 (weight of steel 1 in. square and 1 ft long).

Thickness, in. (mm)	Width, in. (mm)	Hot-Rolled Bars	Cold-Finished Bars
		Flats	
Under ⅝ (16)	Up to 1½ (38), incl	Full section by 8-in. (203-mm) gage length (Fig. 4).	Mill reduced section to 2-in. (51-mm) gage length and approximately 25% less than test specimen width.
	Over 1½ (38)	Full section, or mill to 1½ in. (38 mm) wide by 8-in. (203-mm) gage length (Fig. 4).	Mill reduced section to 2-in. gage length and 1½ in. wide.
⅝ to 1½ (16 to 38), excl	Up to 1½ (38), incl	Full section by 8-in. gage length or machine standard ½ by 2-in. (13 by 51-mm) gage length specimen from center of section (Fig. 5).	Mill reduced section to 2-in. (51-mm) gage length and approximately 25% less than test specimen width or machine standard ½ by 2-in. (13 by 51-mm) gage length specimen from center of section (Fig. 5).
	Over 1½ (38)	Full section, or mill 1½ in. (38 mm) width by 8-in. (203-mm) gage length (Fig. 4) or machine standard ½ by 2-in. gage (13 by 51-mm) gage length specimen from midway between edge and center of section (Fig. 5).	Mill reduced section to 2-in. gage length and 1½ in. wide or machine standard ½ by 2-in. gage length specimen from midway between edge and center of section (Fig. 5).
1½ (38) and over		Full section by 8-in. (203-mm) gage length, or machine standard ½ by 2-in. (13 by 51-mm) gage length specimen from midway between surface and center (Fig. 5).	Machine standard ½ by 2-in. (13 by 51-mm) gage length specimen from midway between surface and center (Fig. 5).

Diameter or Distance Between Parallel Faces, in. (mm)	Hot-Rolled Bars	Cold-Finished Bars
	Rounds, Squares, Hexagons, and Octagons	
Under ⅝	Full section by 8-in. (203-mm) gage length on machine to subsize specimen (Fig. 5).	Machine to sub-size specimen (Fig. 5).
⅝ to 1½ (16 to 38), excl	Full section by 8-in. (203-mm) gage length or machine standard ½ in. by 2-in. (13 by 51-mm) gage length specimen from center of section (Fig. 5).	Machine standard ½ in. by 2-in. gage length specimen from center of section (Fig. 5).
1½ (38) and over	Full section by 8-in. (203-mm) gage length or machine standard ½ in. by 2-in. (13 by 51-mm) gage length specimen from midway between surface and center of section (Fig. 5).	Machine standard ½ in. by 2-in. (13 by 51-mm gage length specimen from midway between surface and center of section (Fig. 5)).
	Other Bar-Size Sections	
All sizes	Full section by 8-in. (203-mm) gage length or prepare test specimen 1½ in. (38 mm) wide (if possible) by 8-in. (203-mm) gage length.	Mill reduced section to 2-in. (51-mm) gage length and approximately 25% less than test specimen width.

TABLE A1.2 Recommended Practice for Selecting Bend Test Specimens for Steel Bar Products

NOTE 1—The length of all specimens is to be not less than 6 in. (150 mm).

NOTE 2—The edges of the specimen may be rounded to a radius not exceeding 1/16 in. (1.6 mm).

Thickness, in. (mm)	Width, in. (mm)	Recommended Size
	Flats	
Up to ½ (13), incl	Up to ¾ (19), incl	Full section.
	Over ¾ (19)	Full section or machine to not less than ¾ in. (19 mm) in width by thickness of specimen.
Over ½ (13)	All	Full section or machine to 1 by ½ in. (25 by 13 mm) specimen from midway between center and surface.

Diameter or Distance Between Parallel Faces, in. (mm)	Recommended Size
Rounds, Squares, Hexagons, and Octagons	
Up to 1½ (38), incl	Full section.
Over 1½ (38)	Machine to 1 by ½-in. (25 by 13-mm) specimen from midway between center and surface.

A2. STEEL TUBULAR PRODUCTS

A2.1 Scope

A2.1.1 This supplement covers test specimens and test methods that are applicable to tubular products and are not covered in the general section of Test Methods and Definitions A 370.

A2.1.2 Tubular shapes covered by this specification include, round, square, rectangular, and special shapes.

A2.2 Tension Test

A2.2.1 *Full-Size Longitudinal Test Specimens*:

A2.2.1.1 As an alternative to the use of longitudinal strip test specimens or longitudinal round test specimens, tension test specimens of full-size tubular sections are used, provided that the testing equipment has sufficient capacity. Snug-fitting metal plugs should be inserted far enough in the end of such tubular specimens to permit the testing machine jaws to grip the specimens properly without crushing. A design that may be used for such plugs is shown in Fig. A2.1. The plugs shall not extend into that part of the specimen on which the elongation is measured (Fig. A2.1). Care should be exercised to see that insofar as practicable, the load in such cases is applied axially. The length of the full-section specimen depends on the gage length prescribed for measuring the elongation.

A2.2.1.2 Unless otherwise required by the product specification, the gage length is 2 in. or 50 mm, except that for tubing having an outside diameter of ⅜ in. (9.5 mm) or less, it is customary for a gage length equal to four times the outside diameter to be used when elongation comparable to that obtainable with larger test specimens is required.

A2.2.1.3 To determine the cross-sectional area of the full-section specimen, measurements shall be recorded as the average or mean between the greatest and least measurements of the outside diameter and the average or mean wall thickness, to the nearest 0.001 in. (0.025 mm) and the cross-sectional area is determined by the following equation:

$$A = 3.1416t(D - t) \quad \text{(A2.1)}$$

where:

A = sectional area, in.^{2}
D = outside diameter, in., and
t = thickness of tube wall, in.

NOTE A2.1—There exist other methods of cross-sectional area determination, such as by weighing of the specimens, which are equally accurate or appropriate for the purpose.

A2.2.2 *Longitudinal Strip Test Specimens*:

A2.2.2.1 As an alternative to the use of full-size longitudinal test specimens or longitudinal round test specimens, longitudinal strip test specimens, obtained from strips cut from the tubular product as shown in Fig. A2.2 and machined to the dimensions shown in Fig. A2.3 are used. For welded structural tubing, such test specimens shall be from a location at least 90° from the weld; for other welded tubular products, such test specimens shall be from a location approximately 90° from the weld. Unless otherwise required by the product specification, the gage length is 2 in. or 50 mm. The test specimens shall be tested using grips that are flat or have a surface contour corresponding to the curvature of the tubular product, or the ends of the test specimens shall be flattened without heating prior to the test specimens being tested using flat grips. The test specimen shown as specimen no. 4 in Fig. 3 shall be used, unless the capacity of the testing equipment or the dimensions and nature of the tubular product to be tested makes the use of specimen nos. 1, 2, or 3 necessary.

NOTE A2.2—An exact formula for calculating the cross-sectional area of specimens of the type shown in Fig. A2.3 taken from a circular tube is given in Test Methods E 8 or E 8M.

A2.2.2.2 The width should be measured at each end of the gage length to determine parallelism and also at the center. The thickness should be measured at the center and used with the center measurement of the width to determine the cross-sectional area. The center width dimension should be recorded to the nearest 0.005 in. (0.127 mm), and the thickness measurement to the nearest 0.001 in.

A2.2.3 *Transverse Strip Test Specimens*:

A2.2.3.1 In general, transverse tension tests are not recommended for tubular products, in sizes smaller than 8 in. in

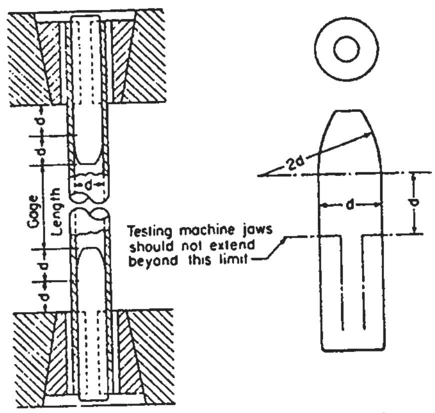
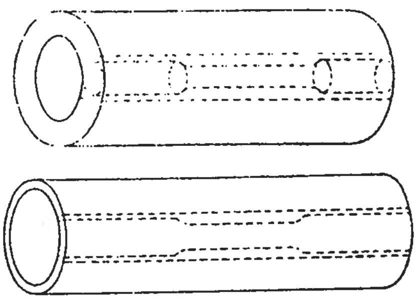
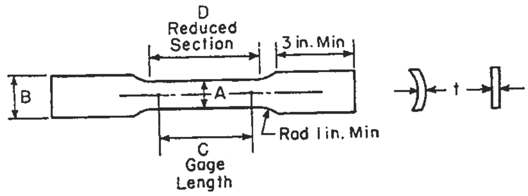


FIG. A2.1 Metal Plugs for Testing Tubular Specimens, Proper Location of Plugs in Specimen and of Specimen in Heads of Testing Machine



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

FIG. A2.2 Location of Longitudinal Tension–Test Specimens in Rings Cut from Tubular Products



DIMENSIONS

Specimen No.	Dimensions, in.			
	A	B	C	D
1	½ ± 0.015	11/16 approximately	2 ± 0.005	2¼ min
2	¾ ± 0.031	1 approximately	2 ± 0.005	2¼ min
			4 ± 0.005	4½ min
3	1 ± 0.062	1½ approximately	2 ± 0.005	2¼ min
			4 ± 0.005	4½ min
4	1½ ± ⅛	2 approximately	2 ± 0.010	2¼ min
			4 ± 0.015	4½ min
			8 ± 0.020	9 min

NOTE 1—Cross-sectional area may be calculated by multiplying *A* and *t*.

NOTE 2—The dimension *t* is the thickness of the test specimen as provided for in the applicable material specifications.

NOTE 3—The reduced section shall be parallel within 0.010 in. and may have a gradual taper in width from the ends toward the center, with the ends not more than 0.010 in. wider than the center.

NOTE 4—The ends of the specimen shall be symmetrical with the center line of the reduced section within 0.10 in.

NOTE 5—Metric equivalent: 1 in. = 25.4 mm.

NOTE 6—Specimens with sides parallel throughout their length are permitted, except for referee testing, provided: (*a*) the above tolerances are used; (*b*) an adequate number of marks are provided for determination of elongation; and (*c*) when yield strength is determined, a suitable extensometer is used. If the fracture occurs at a distance of less than 2*A* from the edge of the gripping device, the tensile properties determined may not be representative of the material. If the properties meet the minimum requirements specified, no further testing is required, but if they are less than the minimum requirements, discard the test and retest.

FIG. A2.3 Dimensions and Tolerances for Longitudinal Strip Tension Test Specimens for Tubular Products

nominal diameter. When required, transverse tension test specimens may be taken from rings cut from ends of tubes or pipe as shown in Fig. A2.4. Flattening of the specimen may be done either after separating it from the tube as in Fig. A2.4 (*a*), or before separating it as in Fig. A2.4 (*b*), and may be done hot or cold; but if the flattening is done cold, the specimen may subsequently be normalized. Specimens from tubes or pipe for which heat treatment is specified, after being flattened either hot or cold, shall be given the same treatment as the tubes or pipe. For tubes or pipe having a wall thickness of less than ¾ in. (19 mm), the transverse test specimen shall be of the form and dimensions shown in Fig. A2.5 and either or both surfaces may be machined to secure uniform thickness. Specimens for transverse tension tests on welded steel tubes or pipe to determine strength of welds, shall be located perpendicular to the welded seams with the weld at about the middle of their length.

A2.2.3.2 The width should be measured at each end of the gage length to determine parallelism and also at the center. The thickness should be measured at the center and used with the

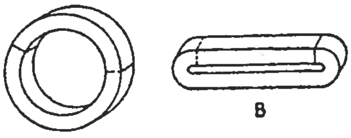
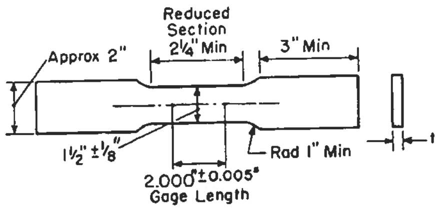


FIG. A2.4 Location of Transverse Tension Test Specimens in Ring Cut from Tubular Products.



NOTE 1—The dimension *t* is the thickness of the test specimen as provided for in the applicable material specifications.

NOTE 2—The reduced section shall be parallel within 0.010 in. and may have a gradual taper in width from the ends toward the center, with the ends not more than 0.010 in. wider than the center.

NOTE 3—The ends of the specimen shall be symmetrical with the center line of the reduced section within 0.10 in.

NOTE 4—Metric equivalent: 1 in. = 25.4 mm.

FIG. A2.5 Transverse Tension Test Specimen Machined from Ring Cut from Tubular Products

center measurement of the width to determine the cross-sectional area. The center width dimension should be recorded to the nearest 0.005 in. (0.127 mm), and the thickness measurement to the nearest 0.001 in. (0.025 mm).

A2.2.4 *Round Test Specimens:*

A2.2.4.1 When provided for in the product specification, the round test specimen shown in Fig. 4 may be used.

A2.2.4.2 The diameter of the round test specimen is measured at the center of the specimen to the nearest 0.001 in. (0.025 mm).

A2.2.4.3 Small-size specimens proportional to standard, as shown in Fig. 4, may be used when it is necessary to test material from which the standard specimen cannot be prepared. Other sizes of small-size specimens may be used. In any such small-size specimen, it is important that the gage length for measurement of elongation be four times the diameter of the specimen (see Note 4, Fig. 4). The elongation requirements for the round specimen 2-in. gage length in the product specification shall apply to the small-size specimens.

A2.2.4.4 For transverse specimens, the section from which the specimen is taken shall not be flattened or otherwise deformed.

A2.2.4.5 Longitudinal test specimens are obtained from strips cut from the tubular product as shown in Fig. A2.2.

A2.3 Determination of Transverse Yield Strength, Hydraulic Ring-Expansion Method

A2.3.1 Hardness tests are made on the outside surface, inside surface, or wall cross-section depending upon product-specification limitation. Surface preparation may be necessary to obtain accurate hardness values.

A2.3.2 A testing machine and method for determining the transverse yield strength from an annular ring specimen, have been developed and described in A2.3.3-8.1.2.

A2.3.3 A diagrammatic vertical cross-sectional sketch of the testing machine is shown in Fig. A2.6.

A2.3.4 In determining the transverse yield strength on this machine, a short ring (commonly 3 in. (76 mm) in length) test specimen is used. After the large circular nut is removed from the machine, the wall thickness of the ring specimen is determined and the specimen is telescoped over the oil resistant rubber gasket. The nut is then replaced, but is not turned down tight against the specimen. A slight clearance is left between the nut and specimen for the purpose of permitting free radial movement of the specimen as it is being tested. Oil under pressure is then admitted to the interior of the rubber gasket through the pressure line under the control of a suitable valve. An accurately calibrated pressure gage serves to measure oil pressure. Any air in the system is removed through the bleeder line. As the oil pressure is increased, the rubber gasket expands which in turn stresses the specimen circumferentially. As the pressure builds up, the lips of the rubber gasket act as a seal to prevent oil leakage. With continued increase in pressure, the ring specimen is subjected to a tension stress and elongates accordingly. The entire outside circumference of the ring specimen is considered as the gage length and the strain is measured with a suitable extensometer which will be described later. When the desired total strain or extension under load is reached on the extensometer, the oil pressure in pounds per square inch is read and by employing Barlow's formula, the unit yield strength is calculated. The yield strength, thus determined, is a true result since the test specimen has not been cold worked by flattening and closely approximates the same condition as the tubular section from which it is cut. Further, the test closely simulates service conditions in pipe lines. One testing machine unit may be used for several different sizes of pipe by the use of suitable rubber gaskets and adapters.

NOTE A2.3—Barlow's formula may be stated two ways:

$$(1)\ P = 2St/D \quad (A2.2)$$

$$(2)\ S = PD/2t \quad (A2.3)$$

where:

P = internal hydrostatic pressure, psi,
S = unit circumferential stress in the wall of the tube produced by the internal hydrostatic pressure, psi,
t = thickness of the tube wall, in., and
D = outside diameter of the tube, in.

A2.3.5 A roller chain type extensometer which has been found satisfactory for measuring the elongation of the ring specimen is shown in Fig. A2.7 and Fig. A2.8. Fig. A2.7 shows the extensometer in position, but unclamped, on a ring specimen. A small pin, through which the strain is transmitted to and measured by the dial gage, extends through the hollow threaded stud. When the extensometer is clamped, as shown in Fig. A2.8, the desired tension which is necessary to hold the instrument in place and to remove any slack, is exerted on the roller chain by the spring. Tension on the spring may be

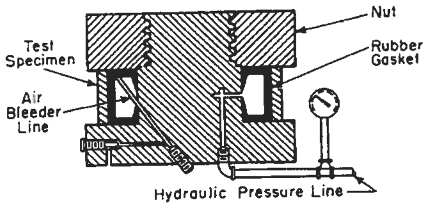


FIG. A2.6 Testing Machine for Determination of Transverse Yield Strength from Annular Ring Specimens

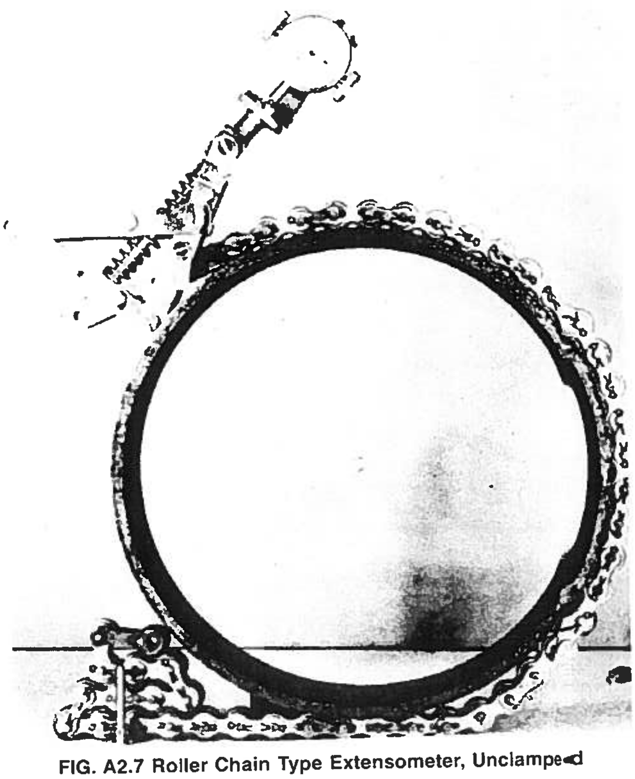


FIG. A2.7 Roller Chain Type Extensometer, Unclamped

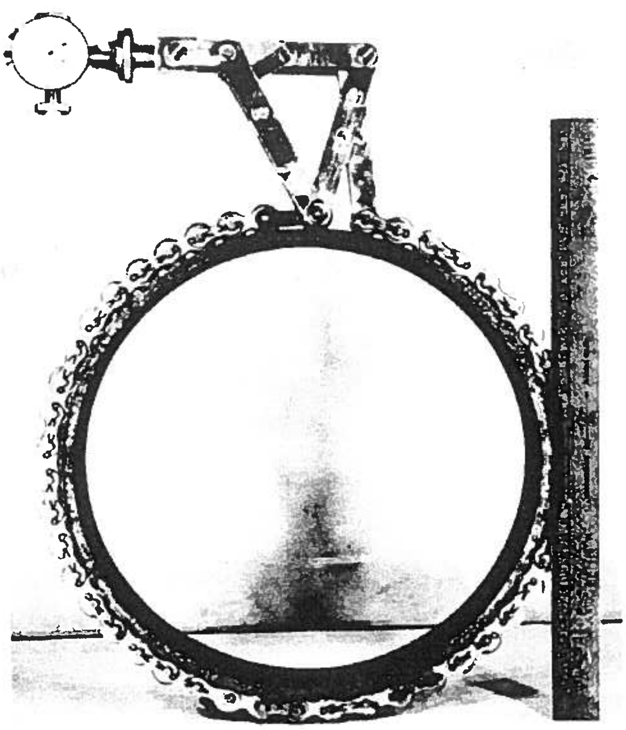


FIG. A2.8 Roller Chain Type Extensometer, Clamped

regulated as desired by the knurled thumb screw. By removing or adding rollers, the roller chain may be adapted for different sizes of tubular sections.

A2.4 Hardness Tests

A2.4.1 Hardness tests are made either on the outside or the inside surfaces on the end of the tube as appropriate.

A2.4.2 The standard 3000-kgf Brinell load may cause too much deformation in a thin-walled tubular specimen. In this case the 500-kgf load shall be applied, or inside stiffening by means of an internal anvil should be used. Brinell testing shall not be applicable to tubular products less than 2 in. (51 mm) in outside diameter, or less than 0.200 in. (5.1 mm) in wall thickness.

A2.4.3 The Rockwell hardness tests are normally made on the inside surface, a flat on the outside surface, or on the wall cross-section depending upon the product limitation. Rockwell hardness tests are not performed on tubes smaller than 5⁄16 in. (7.9 mm) in outside diameter, nor are they performed on the inside surface of tubes with less than 1⁄4 in. (6.4 mm) inside diameter. Rockwell hardness tests are not performed on annealed tubes with walls less than 0.065 in. (1.65 mm) thick or cold worked or heat treated tubes with walls less than 0.049 in. (1.24 mm) thick. For tubes with wall thicknesses less than those permitting the regular Rockwell hardness test, the Superficial Rockwell test is sometimes substituted. Transverse Rockwell hardness readings can be made on tubes with a wall thickness of 0.187 in. (4.75 mm) or greater. The curvature and the wall thickness of the specimen impose limitations on the Rockwell hardness test. When a comparison is made between Rockwell determinations made on the outside surface and determinations made on the inside surface, adjustment of the readings will be required to compensate for the effect of curvature. The Rockwell B scale is used on all materials having an expected hardness range of B0 to B100. The Rockwell C scale is used on material having an expected hardness range of C20 to C68.

A2.4.4 Superficial Rockwell hardness tests are normally performed on the outside surface whenever possible and whenever excessive spring back is not encountered. Otherwise, the tests may be performed on the inside. Superficial Rockwell hardness tests shall not be performed on tubes with an inside diameter of less than 1⁄4 in. (6.4 mm). The wall thickness limitations for the Superficial Rockwell hardness test are given in Table A2.1 and Table A2.2.

A2.4.5 When the outside diameter, inside diameter, or wall thickness precludes the obtaining of accurate hardness values, tubular products shall be specified to tensile properties and so tested.

A2.5 Manipulating Tests

A2.5.1 The following tests are made to prove ductility of certain tubular products:

A2.5.1.1 *Flattening Test*—The flattening test as commonly made on specimens cut from tubular products is conducted by subjecting rings from the tube or pipe to a prescribed degree of flattening between parallel plates (Fig. A2.4). The severity of the flattening test is measured by the distance between the parallel plates and is varied according to the dimensions of the tube or pipe. The flattening test specimen should not be less than 2½ in. (63.5 mm) in length and should be flattened cold to the extent required by the applicable material specifications.

A2.5.1.2 *Reverse Flattening Test*—The reverse flattening test is designed primarily for application to electric-welded tubing for the detection of lack of penetration or overlaps resulting from flash removal in the weld. The specimen consists of a length of tubing approximately 4 in. (102 mm) long which is split longitudinally 90° on each side of the weld. The sample is then opened and flattened with the weld at the point of maximum bend (Fig. A2.9).

TABLE A2.1 Wall Thickness Limitations of Superficial Hardness Test on Annealed or Ductile Materials for Steel Tubular Products[A]
("T" Scale (1⁄16-in. Ball))

Wall Thickness, in. (mm)	Load, kgf
Over 0.050 (1.27)	45
Over 0.035 (0.89)	30
0.020 and over (0.51)	15

[A] The heaviest load recommended for a given wall thickness is generally used.

TABLE A2.2 Wall Thickness Limitations of Superficial Hardness Test on Cold Worked or Heat Treated Material for Steel Tubular Products[A]
("N" Scale (Diamond Penetrator))

Wall Thickness, in. (mm)	Load, kgf
Over 0.035 (0.89)	45
Over 0.025 (0.51)	30
0.015 and over (0.38)	15

[A] The heaviest load recommended for a given wall thickness is generally used.

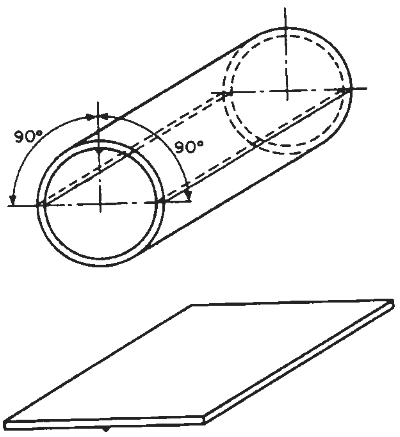


FIG. A2.9 Reverse Flattening Test

A2.5.1.3 *Crush Test*—The crush test, sometimes referred to as an upsetting test, is usually made on boiler and other pressure tubes, for evaluating ductility (Fig. A2.10). The specimen is a ring cut from the tube, usually about 2½ in. (63.5 mm) long. It is placed on end and crushed endwise by hammer or press to the distance prescribed by the applicable material specifications.

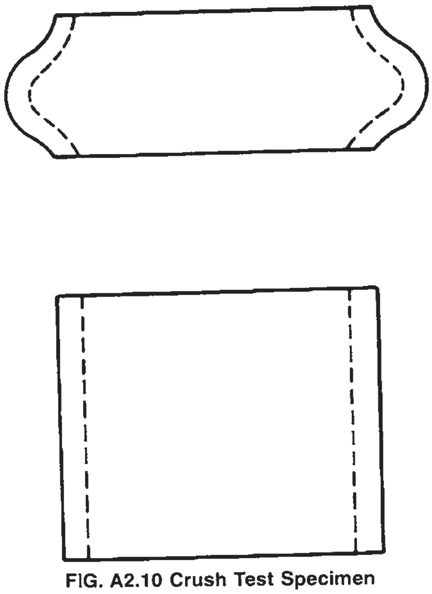


FIG. A2.10 Crush Test Specimen

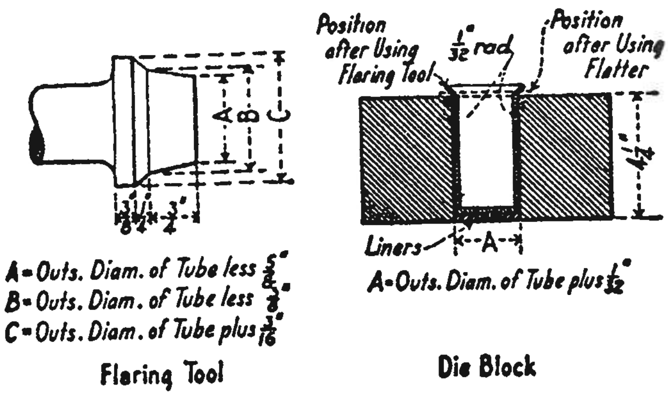
A2.5.1.4 *Flange Test*—The flange test is intended to determine the ductility of boiler tubes and their ability to withstand the operation of bending into a tube sheet. The test is made on a ring cut from a tube, usually not less than 4 in. (100 mm) long and consists of having a flange turned over at right angles to the body of the tube to the width required by the applicable material specifications. The flaring tool and die block shown in Fig. A2.11 are recommended for use in making this test.

A2.5.1.5 *Flaring Test*—For certain types of pressure tubes, an alternate to the flange test is made. This test consists of driving a tapered mandrel having a slope of 1 in 10 as shown in Fig. A2.12 (*a*) or a 60° included angle as shown in Fig. A2.12 (*b*) into a section cut from the tube, approximately 4 in. (100 mm) in length, and thus expanding the specimen until the inside diameter has been increased to the extent required by the applicable material specifications.

A2.5.1.6 *Bend Test*—For pipe used for coiling in sizes 2 in. and under a bend test is made to determine its ductility and the soundness of weld. In this test a sufficient length of full-size pipe is bent cold through 90° around a cylindrical mandrel having a diameter 12 times the nominal diameter of the pipe. For close coiling, the pipe is bent cold through 180° around a mandrel having a diameter 8 times the nominal diameter of the pipe.

A2.5.1.7 *Transverse Guided Bend Test of Welds*—This bend test is used to determine the ductility of fusion welds. The specimens used are approximately 1½ in. (38 mm) wide, at least 6 in. (152 mm) in length with the weld at the center, and are machined in accordance with Fig. A2.13 for face and root bend tests and in accordance with Fig. A2.14 for side bend tests. The dimensions of the plunger shall be as shown in Fig. A2.15 and the other dimensions of the bending jig shall be substantially as given in this same figure. A test shall consist of a face bend specimen and a root bend specimen or two side bend specimens. A face bend test requires bending with the inside surface of the pipe against the plunger; a root bend test requires bending with the outside surface of the pipe against the plunger; and a side bend test requires bending so that one of the side surfaces becomes the convex surface of the bend specimen.

(a) Failure of the bend test depends upon the appearance of cracks in the area of the bend, of the nature and extent described in the product specifications.



NOTE 1—Metric equivalent: 1 in. = 25.4 mm.

FIG. A2.11 Flaring Tool and Die Block for Flange Test

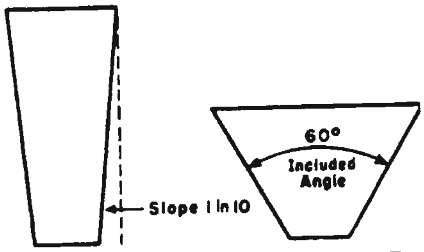
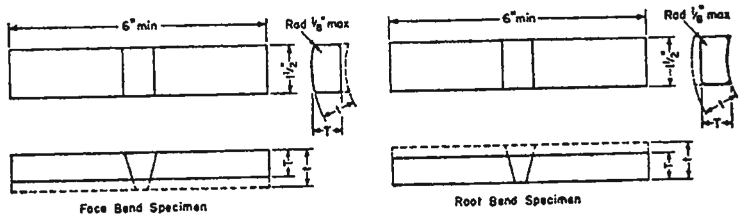


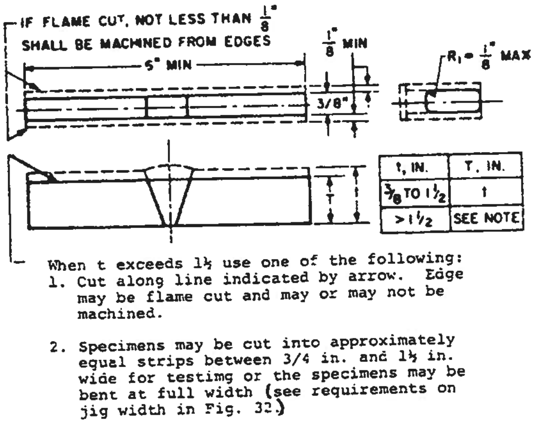
FIG. A2.12 Tapered Mandrels for Flaring Test



NOTE 1—Metric equivalent: 1 in. = 25.4 mm.

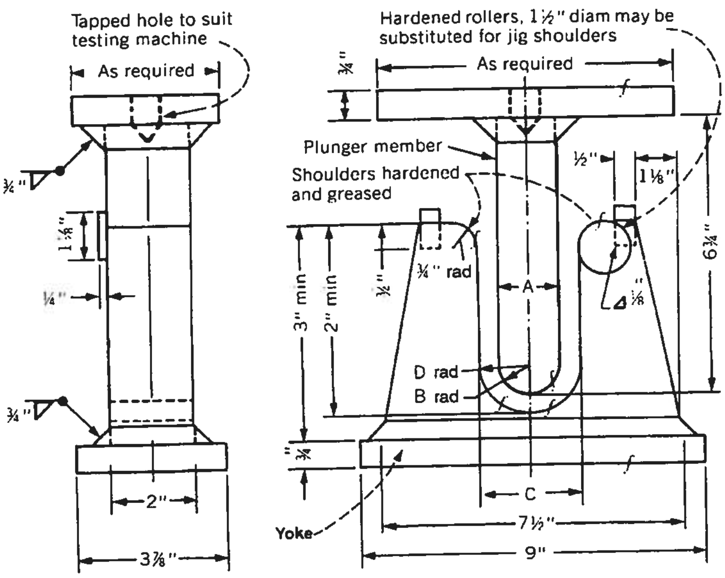
Pipe Wall Thickness (*t*), in.	Test Specimen Thickness, in.
Up to ⅜ , incl	*t*
Over ⅜	⅜

FIG. A2.13 Transverse Face- and Root-Bend Test Specimens



NOTE 1—Metric equivalent: 1 in. = 25.4 mm.

FIG. A2.14 Side-Bend Specimen for Ferrous Materials



NOTE 1—Metric equivalent: 1 in. = 25.4 mm.

Test Specimen Thickness, in.	A	B	C	D	Material
3/8	1½	¾	2⅜	1 3/16	
t	4t	2t	6t + ⅛	3t + 1/16	
3/8	2½	1¼	3⅜	1 11/16	Materials with a specified minimum tensile strength of 95 ksi or greater.
t	6⅔ t	3⅓ t	8⅔ t + ⅛	4½ t + 1/16	

FIG. A2.15 Guided-Bend Test Jig

A3. STEEL FASTENERS

A3.1 Scope

A3.1.1 This supplement covers definitions and methods of testing peculiar to steel fasteners which are not covered in the general section of Test Methods and Definitions A 370. Standard tests required by the individual product specifications are to be performed as outlined in the general section of these methods.

A3.1.2 These tests are set up to facilitate production control testing and acceptance testing with certain more precise tests to be used for arbitration in case of disagreement over test results.

A3.2 Tension Tests

A3.2.1 It is preferred that bolts be tested full size, and it is customary, when so testing bolts to specify a minimum ultimate load in pounds, rather than a minimum ultimate strength in pounds per square inch. Three times the bolt nominal diameter has been established as the minimum bolt length subject to the tests described in the remainder of this section. Sections A3.2.1.1-A3.2.1.3 apply when testing bolts full size. Section A3.2.1.4 shall apply where the individual product specifications permit the use of machined specimens.

A3.2.1.1 *Proof Load*— Due to particular uses of certain classes of bolts it is desirable to be able to stress them, while in use, to a specified value without obtaining any permanent set. To be certain of obtaining this quality the proof load is specified. The proof load test consists of stressing the bolt with a specified load which the bolt must withstand without permanent set. An alternate test which determines yield strength of a full size bolt is also allowed. Either of the following Methods, 1 or 2, may be used but Method 1 shall be the arbitration method in case of any dispute as to acceptance of the bolts.

A3.2.1.2 *Proof Load Testing Long Bolts*—When full size tests are required, proof load Method 1 is to be limited in application to bolts whose length does not exceed 8 in. (203 mm) or 8 times the nominal diameter, whichever is greater. For bolts longer than 8 in. or 8 times the nominal diameter, whichever is greater, proof load Method 2 shall be used.

(a) *Method 1, Length Measurement*—The overall length of a straight bolt shall be measured at its true center line with an instrument capable of measuring changes in length of 0.0001 in. (0.0025 mm) with an accuracy of 0.0001 in. in any 0.001-in. (0.025-mm) range. The preferred method of measuring the length shall be between conical centers machined on the center line of the bolt, with mating centers on the measuring anvils. The head or body of the bolt shall be marked so that it can be placed in the same position for all measurements. The bolt shall be assembled in the testing equipment as outlined in A3.2.1.4, and the proof load specified in the product specification shall be applied. Upon release of this load the length of the bolt shall be again measured and shall show no permanent elongation. A tolerance of ±0.0005 in. (0.0127 mm) shall be allowed between the measurement made before loading and that made after loading. Variables, such as straightness and thread alignment (plus measurement error), may result in apparent elongation of the fasteners when the proof load is initially applied. In such cases, the fastener may be retested using a 3 percent greater load, and may be considered satisfactory if the length after this loading is the same as before this loading (within the 0.0005-in. tolerance for measurement error).

A3.2.1.3 *Proof Load-Time of Loading*—The proof load is to be maintained for a period of 10 s before release of load, when using Method 1.

(*1*) *Method 2, Yield Strength*—The bolt shall be assembled in the testing equipment as outlined in A3.2.1.4. As the load is applied, the total elongation of the bolt or any part of the bolt which includes the exposed six threads shall be measured and recorded to produce a load-strain or a stress-strain diagram. The load or stress at an offset equal to 0.2 percent of the length of bolt occupied by 6 full threads shall be determined by the method described in 13.2.1 of these methods, A 370. This load or stress shall not be less than that prescribed in the product specification.

A3.2.1.4 *Axial Tension Testing of Full Size Bolts*—Bolts are to be tested in a holder with the load axially applied between the head and a nut or suitable fixture (Fig. A3.1), either of which shall have sufficient thread engagement to develop the full strength of the bolt. The nut or fixture shall be assembled on the bolt leaving six complete bolt threads unengaged between the grips, except for heavy hexagon structural bolts which shall have four complete threads unengaged between the grips. To meet the requirements of this test there shall be a tensile failure in the body or threaded section with no failure at the junction of the body, and head. If it is necessary to record or report the tensile strength of bolts as psi values the stress area shall be calculated from the mean of the mean root and pitch diameters of Class 3 external threads as follows:

$$A_s = 0.7854\,[D - (0.9743/n)]^2 \qquad (A3.1)$$

where:

A_s = stress area, in.^{2},
D = nominal diameter, in., and
n = number of threads per inch.

A3.2.1.5 *Tension Testing of Full-Size Bolts with a Wedge*—The purpose of this test is to obtain the tensile strength and demonstrate the "head quality" and ductility of a bolt with a standard head by subjecting it to eccentric loading. The ultimate load on the bolt shall be determined as described in A3.2.1.4, except that a 10° wedge shall be placed under the same bolt previously tested for the proof load (see A3.2.1.1). The bolt head shall be so placed that no corner of the hexagon or square takes a bearing load, that is, a flat of the head shall be aligned with the direction of uniform thickness of the wedge (Fig. A3.2). The wedge shall have an included angle of 10°

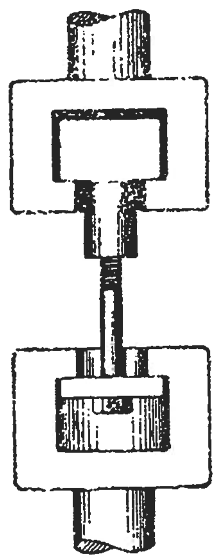
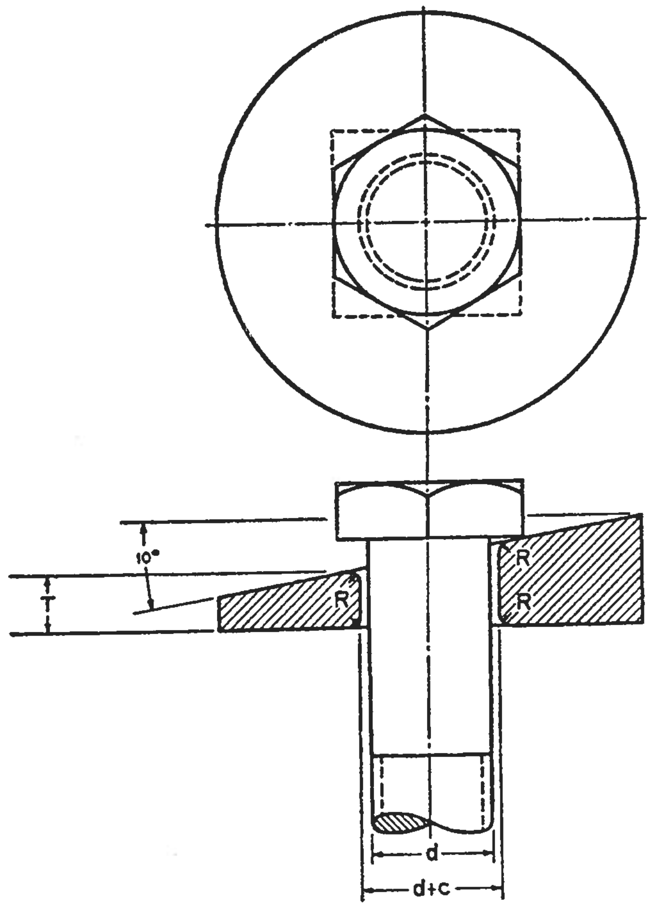


FIG. A3.1 Tension Testing Full-Size Bolt



c = Clearance of wedge hole
d = Diameter of bolt
R = Radius
T = Thickness of wedge at short side of hole equal to one-half diameter of bolt

FIG. A3.2 Wedge Test Detail

between its faces and shall have a thickness of one-half of the nominal bolt diameter at the short side of the hole. The hole in the wedge shall have the following clearance over the nominal size of the bolt, and its edges, top and bottom, shall be rounded to the following radius:

Nominal Bolt Size, in.	Clearance in Hole, in. (mm)	Radius on Corners of Hole, in. (mm)
¼ to ½	0.030 (0.76)	0.030 (0.76)
9⁄16 to ¾	0.050 (1.3)	0.060 (1.5)
⅞ to 1	0.063 (1.5)	0.060 (1.5)
1⅛ to 1¼	0.063 (1.5)	0.125 (3.2)
1⅜ to 1½	0.094 (2.4)	0.125 (3.2)

A3.2.1.6 *Wedge Testing of HT Bolts Threaded to Head*—For heat-treated bolts over 100 000 psi (690 MPa) minimum tensile strength and that are threaded 1 diameter and closer to the underside of the head, the wedge angle shall be 6° for sizes ¼ through ¾ in. (6.35 to 19.0 mm) and 4° for sizes over ¾ in.

A3.2.1.7 *Tension Testing of Bolts Machined to Round Test Specimens*:

(1) Bolts under 1½ in. (38 mm) in diameter which require machined tests shall preferably use a standard ½-in., (13-mm) round 2-in. (50-mm) gage length test specimen (Fig. 4); however, bolts of small cross-section that will not permit the taking of this standard test specimen shall use one of the small-size-specimens-proportional-to-standard (Fig. 4) and the specimen shall have a reduced section as large as possible. In all cases, the longitudinal axis of the specimen shall be concentric with the axis of the bolt: the head and threaded section of the bolt may be left intact, as in Fig. A3.3 and Fig. A3.4, or shaped to fit the holders or grips of the testing machine so that the load is applied axially. The gage length for measuring the elongation shall be four times the diameter of the specimen.

(2) For bolts 1½ in. and over in diameter, a standard ½-in. round 2-in. gage length test specimen shall be turned from the bolt, having its axis midway between the center and outside surface of the body of the bolt as shown in Fig. A3.5.

(3) Machined specimens are to be tested in tension to determine the properties prescribed by the product specifications. The methods of testing and determination of properties shall be in accordance with Section 13 of these test methods.