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Standard 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.

These methods have been approved for use by agencies of the Department of Defense and for listing in the DoD Index of Specifications and Standards.

ε1 NOTE—Paragraph 18.2 was editorially changed in May 1979.
ε2 NOTE—Fig. 21 was editorially corrected in October 1980.

1. Scope

1.1 These methods[2] cover procedures and definitions for the mechanical testing of wrought and cast steel products. 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 where 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 and 17
Rockwell	18
Impact	19 to 23

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

	Sections
Bar Products (Supplement I)	S 1 to S 4
Tubular Products (Supplement II)	S 5 to S 9
Fasteners (Supplement III)	S 10 to S 15
Round Wire Products (Supplement IV)	S 16 to S 22
Significance of Notched Bar Impact Testing (Supplement V)	S 23 to S 28
Converting Percentage Elongation of Round Specimens to Equivalents for Flat Specimens (Supplement VI)	S 29 to S 31
Testing Seven Wire Stress-Relieved Strand (Supplement VII)	S 32 to S 36
Rounding Test Data (Supplement VIII)	

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

2. Applicable Documents

2.1 *ASTM Standards:*

A 416 Specification for Uncoated Seven-Wire Stress-Relieved Steel Strand for Prestressed Concrete[3]

E 4 Practices for Load Verification of Testing Machines[4]

E 6 Definitions of Terms Relating to Methods of Mechanical Testing[4]

E 8 Methods of Tension Testing of Metallic Materials[4]

E 10 Test Method for Brinell Hardness of Metallic Materials[4]

E 18 Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials[4]

E 23 Methods for Notched Bar Impact Testing of Metallic Materials[4]

E 83 Method of Verification and Classification of Extensometers[4]

E 110 Test Method for Indentation Hardness of Metallic Materials by Portable Hardness Testers[4]

E 208 Method for Conducting Drop-Weight Test to Determine Nil-Ductility Transition Temperature of Ferritic Steels[4]

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[1] These methods are under the jurisdiction of ASTM Committee A-1 on Steel, Stainless Steel and Related Alloys and are the direct responsibility of Subcommittee A01.13 on Mechanical Testing.

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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] *Annual Book of ASTM Standards*, Vol 01.04.

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

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 (Figs. 1, 2(*a*), and 2(*b*)).

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. 2(*a*)).

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 (Figs. 2(*a*), 2(*b*), 2(*c*), and 2(*d*).

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 Definitions E 6.

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

6. Test Specimen Parameters

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

6.1.1 *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 Figs. 1 and 2).

6.1.2 *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.

6.1.3 *Cast Steels*—Test coupons for castings from which tension test specimens are prepared shall be attached to the castings where practicable. If the design of the casting is such that test coupons should not be attached thereon, test coupons shall be cast attached to separate cast blocks (Fig. 3 and Table 1).

6.2 *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. 4 to 7, 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.

6.3 *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.

6.4 *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.

6.5 *Measurement of Dimensions of Test Specimens:*

6.5.1 *Standard Rectangular Tension Test Specimens*—These forms of specimens are shown in Fig. 4. 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. 4. The center thickness dimension shall be measured to the nearest 0.001 in. for both specimens.

6.5.2 *Standard Round Tension Test Specimens*—These forms of specimens are shown in Figs. 5 and 6. To determine the cross-sectional area, the diameter shall be measured at the center of the gage length to the nearest 0.001 in.

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

6.6.1 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.

6.6.2 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.

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

7. Plate-Type Specimen

7.1 The standard plate-type test specimen is shown in Fig. 4. 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 1—When called for in the product specification, the 8-in. gage length specimen of Fig. 4 may be used for sheet and strip material.

8. Sheet-Type Specimen

8.1 The standard sheet-type test specimen is shown in Fig. 4. 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 7.

9. Round Specimens

9.1 The standard 0.500-in. (12.5-mm) diameter round test specimen shown in Fig. 5 is used quite generally for testing metallic materials, both cast and wrought.

9.2 Figure 5 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. 4 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. 5).

9.3 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. Figure 6 shows specimens with various types of ends that have given satisfactory results.

10. Gage Marks

10.1 The specimens shown in Figs. 4, 5, and 7 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. 4, one or more sets of 8-in. gage marks may be used, intermediate marks within the gage length being optional. Rectangular 2-in. gage length specimens, Fig. 4, and round specimens, Fig. 5, are gage marked with a double-pointed center punch or scribe marks. In both cases the gage points shall be approximately equidistant from the center of the length of the reduced section. These same precautions shall be observed when the test specimen is full section.

11. Testing Apparatus and Operations

11.1 *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.

11.2 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 2—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.

11.3 *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. Gripping of the specimen shall be restricted to the section outside the gage length. In the case of certain sections tested in full size, nonaxial loading is unavoidable and in such cases shall be permissible.

11.4 *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), or (*2*) in terms of rate of separation of the two heads of the testing machine under load, or (*3*) in terms of rate of stressing the specimen. Speed of testing may also be expressed in terms of rate of straining the specimen. However, it is not practicable to control the rate of straining on machines currently used in production testing. The following limitations on the speed of testing are recommended as adequate for most steel products:

11.4.1 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 rate of separation of the crossheads under load shall be adjusted so as not to exceed $^1/_{16}$ in. per min per inch of gage length, 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 rate of separation of the heads under load shall not exceed $^1/_2$ in. per min per inch of gage length. In any event the minimum speed of testing shall not be less than $^1/_{10}$ of the specified maximum rates for determining yield point or yield strength and tensile strength.

11.4.2 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.

11.4.3 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.

12. Definitions

12.1 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 Definitions E 6.

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. 8), or the stress at which the curve drops as the yield point (Fig. 8).

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 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 (Notes 3 and 4) to the specimen. When the load producing a specified extension (Note 5) is reached record the stress corresponding to the load as the yield point, and remove the extensometer (Fig. 9).

NOTE 3—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 4—Reference should be made to Method E 83.

NOTE 5—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.

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 may be drawn. Then on the stress-strain diagram (Fig. 10) 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 reporting values of yield strength obtained by this method, the specified value of "offset" used should be stated in parentheses after the term yield strength, thus:

Yield strength (0.2% offset)
= 52 000 psi (360 MPa)

In using this method, a minimum extensometer magnification of 250 to 1 is required. A Class B1 extensometer meets this requirement (see Note 5). See also Note 7 for automatic devices.

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 7) 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. The total strain can be obtained satisfactorily by use of a Class B1 extensometer (Notes 3 and 4).

NOTE 6—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 7—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:

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

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 percent of the gage length for gage lengths over 2 in. A percentage scale reading to 0.5 percent 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 reporting 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.

13.5 *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 and 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.

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, 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. Tables 3A, 3B, 3C, and 3D are for the conversion of hardness measurements from one scale to another or to approximate tensile stength. 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.

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:

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

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

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 Supplement II on Steel Tubular Products, Section S 8). Other loads and different size indentors may be used when specified. In reporting 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. When agreed upon, hardness tests can be substituted for tension tests in order to expedite testing of a large number of duplicate pieces from the same lot.

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 within 3 percent.

16.2.2 *Micrometer Microscope*—The micrometer microscope or equivalent device for measuring diameter or depth of indentation is adjusted so that throughout the range covered the error of reading does not exceed 0.02 mm.

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 0.01 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 three times the diameter of the indentation.

16.4.2 Apply the load for a minimum of 10 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.

16.4.4 Do not use a steel ball on steels having a hardness over 444 HB nor a carbide ball over 627 HB. The Brinell test is not recommended for materials having a HB over 627.

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

17. Portable Hardness Test

17.1 *Portable Testers*—Under certain circumstances, it may be desirable to substitute a portable Brinell testing instrument, which is calibrated to give equivalent results to those of a standard Brinell machine on a comparison test bar of approximately the same hardness as the material to be tested.

17.2 *Detailed Procedure*—For detailed requirements of the portable test, reference shall be made to the latest revision of Method E 110.

18. Rockwell Test

18.1 *Description:*

18.1.1 In this test a hardness value is obtained by using a direct-reading testing machine which measures hardness 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 read directly on the dial gage. 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

18.1.2 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

18.2 *Reporting Hardness*—In reporting hardness values, the hardness number should always precede the scale symbol, 96 HRB, 40 HRC, 75 HR15N, or 77 HR30T.

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

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

CHARPY IMPACT TESTING

18. Description

19.1 A Charpy impact test is a dynamic test in which a selected specimen, machined or surface ground and notched, is struck and broken by a single blow in a specially designed testing machine and the energy absorbed in breaking the specimen is measured. The energy values determined are qualitative comparisons on a selected specimen and although frequently specified as an acceptance criterion, they cannot be converted into energy figures that would serve for engineering calculations. Percentage shear fracture and mils of lateral expansion opposite the notch are other frequently used criteria of acceptance for Charpy V-notch impact test specimens.

19.2 Testing temperatures other than ambient temperature are often specified in the individual product specifications. Although the testing temperature is sometimes governed by the service temperature, the two may not be identical.

19.3 Further information on the significance of impact testing appears in Supplement V.

20. Test Specimens

20.1 *Selection and Number of Tests:*

20.1.1 Unless otherwise specified, longitudinal test specimens shall be used with the notch perpendicular to the surface of the object being tested.

20.1.2 An impact test shall consist of three specimens taken from a single test coupon or test location.

20.2 *Size and Type:*

20.2.1 The type of specimen desired, Charpy V-notch Type A or Charpy keyhole notch Type B, shown in Fig. 11, should be specified.

20.2.2 For material less than 7/16 in. (11 mm) thick, subsize test specimens shall be used. They shall be made to the following dimensions and to the tolerances shown in Fig. 11:

10 by 7.5 mm
10 by 6.7 mm
10 by 5 mm
10 by 3.3 mm
10 by 2.5 mm

The base of the notch shall be perpendicular to the 10-mm-wide face.

20.2.3 When subsize specimens are required, the specified energy level or test temperature, or both, shall be reduced as agreed upon by purchaser and supplier.

NOTE 9—The Charpy U-notch specimen may be substituted for the keyhold specimen. A sketch of the U-notch specimen may be found as Fig. 4 (Specimen Type C) in Methods E 23.

20.3 *Notch Preparation:*

20.3.1 Particular attention must be paid to the machining of V-notches as it has been demonstrated that extremely minor variations in notch radius may result in very erratic test data. Tool marks at the bottom of the notch must be carefully avoided.

20.3.2 Keyhole notches shall be made by drilling the round hole and then cutting the slot by any feasible means. The drilling must be done carefully with a slow feed. Care must also be exercised in cutting the slot to see that the surface of the drilled hole is not damaged.

21. Testing Apparatus and Conditions

21.1 *General Characteristics:*

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, so that the energy of the blow is fixed and known. The height to which the pendulum rises in its swing after breaking the specimen is measured and used to determine the residual energy of the pendulum. The specimen is supported horizontally as a simple beam with the axis of the notch vertical. It is struck in the middle of the face opposite the notch.

21.1.2 Charpy machines used for testing steel generally strike the specimen with an energy of from 220 to 265 ft·lbf (298 to 359 J) and a linear velocity at the point of impact of 16 to 19 ft (4.88 to 5.80 m)/s. Sometimes machines of lighter capacity are used.

21.2 *Calibration (Accuracy and Sensitivity):*

21.2.1 Charpy impact machines shall be calibrated and adjusted in accordance with the requirements of the latest revision of Methods E 23.

21.2.2 The indicator should have an error not greater than 1 ft·lbf (1.4 J) as calibrated by the prescribed procedure.

21.2.3 The dimensions of the pendulum should be such that the center of percussion is at the point of impact with an error not greater than 1 percent of the distance from the axis of rotation to the point of impact.

21.2.4 The dimensions of the specimen supports and striking edge shall conform to Fig. 12.

21.3 *Temperature:*

21.3.1 The effect of variations in temperature on Charpy test results is sometimes very great and this variable shall be closely controlled. The actual temperature at which each specimen is broken shall be reported.

21.3.2 Tests are often specified to be run at low temperatures. These low temperatures can be obtained readily in the laboratory by the use of chilled liquids such as: water, ice plus water, dry ice plus organic solvents, liquid nitrogen, or chilled gases. Specimens to be tested at low temperatures shall be held at the specified temperature for at least 5 min in liquid coolants and 60 min in gaseous environments.

21.3.3 For elevated-temperature tests, the specimens shall preferably be immersed in an agitated oil, or other suitable liquid bath and held at temperature for at least 10 min; if samples are heated in an oven they must be held in the oven for at least 60 min.

21.3.4 When tested at temperatures other than ambient, specimens shall be inserted in the machine and broken within 5 s so as to minimize the change of temperature prior to breaking.

21.3.5 Tongs for handling the test specimens, and centering devices used to ensure proper location of the test on the anvil of the impact tester, shall be at the same relative temperature as the test specimen prior to each test so as not to affect the temperature of the test specimen at the notch.

22. Test Results

22.1 The result of an impact test shall be the average (arithmetic mean) of the results of the three specimens.

22.2 When the acceptance criteria are based on absorbed energy, not more than one specimen may exhibit a value below the specified minimum average, and in no case shall an individual value be below either two thirds of the specified minimum average or 5 ft·lbf (6.8 J), whichever is greater, subject to the retest provisions of 22.2.1.

22.2.1 If more than one specimen is below the specified minimum average, or if one value is below two thirds of the specified minimum average, a retest of three additional specimens shall be made, each of which shall have a value equal to or exceeding the specified minimum average value.

22.3 When the acceptance criteria are based on lateral expansion, the value for each of the specimens must equal or exceed the specified minimum value subject to the retest provision of 22.3.1.

22.3.1 If the value on one specimen falls below the specified minimum value, and not below two thirds of the specified minimum value, and if the average of the three specimens equals or exceeds the specified minimum value, a retest of three additional specimens shall be made. The value for each of the three retest specimens must equal or exceed the specified minimum value.

23. Acceptance Criteria

23.1 *Impact Strength*—In some applications, impact tests are specified to determine the behavior of the metal when subjected to a single application of a load that produces multiaxial stresses associated with a notch with high rates of loading, in some cases at high or low temperature. Data are reported in terms of foot-pounds of absorbed energy at the test temperature.

23.2 *Ductile-to-Brittle Transition Temperature*—Body-centered-cubic or ferritic alloys exhibit a significant change in behavior when impact tested over a range of temperatures. At elevated temperatures, impact specimens fracture by a shear mechanism absorbing large amounts of energy; at low temperatures they fracture brittlely by a cleavage mechanism absorbing little energy. The transition from one type of behavior to the other has been defined in various ways for specification purposes: (*1*) the temperature corresponding to a specific energy level; (*2*) the temperature at which Charpy V-notch specimens exhibit some specific value of cleavage (shiny, facetted appearance, often termed brittle or crystalline) and shear (often termed ductile or fibrous) fractures. This temperature is commonly called the fracture appearance transition temperature or $FATT_n$ where "*n*" is the percentage of shear fracture. $FATT_{50}$ is most frequently specified; (*3*) the temperature at which the lateral expansion (increase in specimen width on the compression side, opposite the notch, of the fractured Charpy V-notch specimen, Fig. 13) is some specified amount measured in thousandths of an inch (mils).

23.2.1 *Energy Level*—Energy level as determined on the Charpy V-notch impact test has been shown to have fairly good correlation with service failures and also with the nil-ductility transition temperature determined by the drop-weight test (Method E 208). Specific requirements should be based on material capability and either service experience or correlations with the drop weight test or other valid tests for fracture toughness. The test temperature must be specified.

23.2.2 *Fracture Appearance Transition Temperature, $FATT_n$:*

23.2.2.1 *Determination of Percent Shear Fracture*—The percentage of shear fracture may be determined by any of the following methods: (*1*) Measure the length and width of the cleavage portion of the fracture surface, as shown in Fig. 14, and determine the percent shear from either Table 4 or Table 5 depending on the units of measurement; (*2*) compare the appearance of the fracture of the specimen with a fracture appearance chart such as that shown in Fig. 15; (*3*) magnify the fracture surface and compare it to a precalibrated overlay chart or measure the percent shear fracture by means of a planimeter; or (*4*) photograph the fracture surface at a suitable magnification and measure the percent shear fracture by means of a planimeter.

23.2.2.2 *Determination of Transition Temperature*—For determining the transition temperature, break at least four specimens that have been taken from comparable locations. Break each specimen at a different temperature, but in a range of temperature that will produce fractures within the range of ±25 percent of the specified value, *n*, of shear. Plot the percent shear fracture against the test temperature and determine the transition by graphic interpolation (extrapolation is not permitted).

23.2.3 *Mils of Lateral Expansion:*

23.2.3.1 *Determination of Lateral Expansion*—The method for measuring lateral expansion must take into account the fact that the fracture path seldom bisects the point of maximum expansion on both sides of a specimen. One half of a broken specimen may include the maximum expansion for both sides, one side only, or neither. The technique used must therefore provide an expansion value equal to the sum of the higher of the two values obtained for each side by measuring the two halves separately. The amount of expansion on each side of each half must be measured relative to the plane defined by the undeformed portion of the side of the specimen. Expansion may be measured by using a gage similar to that shown in Figs. 16 and 17. Measure the two broken halves individually. First, though, check the sides perpendicular to the notch to ensure that no burrs were formed on these sides during impact testing; if such burrs exist, they must be removed, for example, by rubbing on emery cloth, making sure that the protrusions being measured are not rubbed during the removal of the burr. Next, place the halves together so that the compression sides are facing one another. Take one half and press it firmly against the reference supports, with the protrusion against the gage anvil. Note the reading, then repeat this step with the other broken half, ensuring that the same side of the specimen is measured. The larger of the two values is the expansion of that side of the specimen. Next, repeat this procedure to measure the protrusions on the opposite side, then add the larger values obtained for each side. Measure each specimen.

NOTE 10—Examine each fracture surface to ascertain that the protrusions have not been damaged by contacting the anvil, machine mounting surface, etc. Such samples should be discarded since this may cause erroneous readings.

23.2.3.2 *Determination of Transition Temperature*—For determining the transition temperature, break a sufficient number of specimens over a range of temperatures such that the temperature producing the specified lateral expansion may be determined by graphic interpolation (extrapolation is not permitted).

23.3 *Report*—Test reports shall include the test temperature and energy value (foot-pounds) for each test specimen broken. When specified in the product specification the percent shear fracture or mils of lateral expansion, or both, shall also be reported for each test specimen broken.

SUPPLEMENTS

I. STEEL BAR PRODUCTS

S1. Scope

S1.1 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 methods.

S2. Orientation of Test Specimens

S2.1 Carbon steel bars and bar-size shapes, due to their relatively small cross-sectional dimensions, are customarily tested in the longitudinal direction.

S2.2 Alloy steel bars and bar-size shapes are usually 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.

S3. Tension Test

S3.1 *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 1/2 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.

S3.2 *Alloy Steel Bars*—Alloy steel bars are usually not tested in the as-rolled condition.

S3.3 When tension tests are specified, the recommended practice for selecting test specimens for hot-rolled and cold-finished steel bars of various sizes shall be in accordance with Table 7, unless otherwise specified.

S4. Bend Test

S4.1 When bend tests are specified, the recommended practice for hot-rolled and cold-finished steel bars shall be in accordance with Table 6.

II. STEEL TUBULAR PRODUCTS

S5. Scope

S5.1 This supplement covers definitions and methods of testing peculiar to tubular products which are not covered in the general section of these methods.

S6. Tension Test

S6.1 *Longitudinal Test Specimens:*

S6.1.1 It is standard practice to use tension test specimens of full-size tubular sections within the limit of the testing equipment (Fig. 20 (*d*)). 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. 18. The plugs shall not extend into that part of the specimen on which the elongation is measured (Fig. 18). 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.

S6.1.2 Unless otherwise required by the individual product specification, the gage length for furnace-welded pipe is normally 8 in. (200 mm), except that for nominal sizes ¾ in. and smaller, the gage length shall be as follows:

Nominal Size, in.	Gage Length, in. (mm)
$^3/_4$ and $^1/_2$	6 (150)
$^3/_8$ and $^1/_4$	4 (100)
$^1/_8$	2 (50)

S6.1.3 For seamless and electric-welded pipe and tubes the gage length is 2 in. However, for tubing having an outside diameter of $^3/_8$ in. (10 mm) or less, it is customary to use a gage length equal to four times the outside diameter when elongation values comparable to larger specimens are required.

S6.1.4 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:

$$A = 3.1416t(D - t)$$

where:

A = sectional area, in.^{2}

D = outside diameter, in., and

t = thickness of tube wall, in.

NOTE 11—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.

S6.2 *Longitudinal Strip Test Specimens:*

S6.2.1 For larger sizes of tubular products which cannot be tested in full-section, longitudinal test specimens are obtained from strips cut from the tube or pipe as indicated in Fig. 19. For furnace-welded tubes or pipe the 8-in. gage length specimen as shown in Fig. 20 (*b*), or with both edges parallel as in Fig. 20 (*a*) is standard, the specimen being located at approximately 90 deg from the weld. For seamless and electric-welded tubes or pipe, the 2-in. gage length specimen as shown in Fig. 20 (*c*) is standard, the specimen being located approximately 90 deg from the weld in the case of electric-welded tubes. The specimen shown in Fig. 20 (*a*) may be used as an alternate for seamless and electric-welded tubes or pipe. Specimens of the type shown in Fig. 20 (*a*), (*b*), (*c*), may be tested with grips having a surface contour corresponding to the curvature of the tubes. When grips with curved faces are not available, the ends of the specimens may be flattened without heating. Standard tension test specimens, as shown in specimen No. 4 of Fig. 21, are nominally $1^1/_2$ in. (38 mm) wide in the gage length section. When sub-size specimens are necessary due to the dimensions and character of the material to be tested, specimens 1, 2, or 3 shown in Fig. 21 where applicable, are considered standard. For tubes ¾ in. (19 mm) and over in wall thickness, the test specimen shown in Fig. 5 (Note 12) may be used.

NOTE 12—Standard round tension test specimen with 2-in. gage length.

S6.2.2 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. When the specimen shown in Fig. 5 (Note 12) is used, the diameter is measured at the center of the specimen to the nearest 0.001 in. (0.025 mm).

S6.3 *Transverse Test Specimens.*

S6.3.1 In general, transverse tension tests are not recommended for tubular products, in sizes smaller than 8 in. in nominal diameter. When required, transverse tension test specimens may be taken from rings cut from ends of tubes or pipe as shown in Fig. 22. Flattening of the specimen may be done either after separating it from the tube as in Fig. 22 (*a*), or before separating it as in Fig. 22 (*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. 23 and either or both surfaces may be machined to secure uniform thickness. For tubes having a sufficiently heavy wall thickness the test specimen shown in Fig. 5 (Note 12) may be used. The elongation requirements for the 2-in. gage length in the product specification shall apply to the gage length as specified in Fig. 5. 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.

S6.3.2 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 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). When the specimen shown in Fig. 5 (Note 12) is used, the diameter is measured at the center of the specimen to the nearest 0.001 in.

S7. Determination of Transverse Yield Strength, Hydraulic Ring-Expansion Method

S7.1 Until recently, the transverse yield strength, when required on tubular products, has been determined, as described in the general section of these methods, from standard tension test coupons cut transversely from the tubular sections. Due to the curvature on such coupons it is necessary to cold straighten them. It has long been recognized that the cold work introduced by straightening changes the mechanical properties so that the yield strength obtained is not truly representative of the yield strength in the original tubular section. The transverse yield strength is highly important on some classes of tubular products, such as line pipe, and a method for determining the true yield strength has been desirable for some time.

S7.2 A testing machine and method for determining the transverse yield strength from an annular ring specimen, have been developed and described in S7.3 through S7.5.

S7.3 A diagrammatic vertical cross-sectional sketch of the testing machine is shown in Fig. 24.

S7.4 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 13—Barlow's formula may be stated two ways:

(*1*) $P = 2St/D$

(*2*) $S = PD/2t$

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.

S7.5 A roller chain type extensometer which has been found satisfactory for measuring the elongation of the ring specimen is shown in Figs. 25 and 26. Figure 25 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. 26, 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 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.

S8. Hardness Tests

S8.1 Hardness tests are made either on the outside or the inside surfaces on the end of the tube as appropriate.

S8.2 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.

S8.3 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 B 0 to B 100. The Rockwell C scale is used on material having an expected hardness range of C 20 to C 68.

S8.4 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 ¼ in. (6.4 mm). The wall thickness limitations for the Superficial Rockwell hardness test are given in Tables 8 and 9.

S8.5 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.

S9. Manipulating Tests

S9.1 The following tests are made to prove ductility of certain tubular products:

S9.1.1 *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. 22). 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 $2^1/_2$ in. (63.5 mm) in length and should be flattened cold to the extent required by the applicable material specifications.

S9.1.2 *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 deg on each side of the weld. The sample is then opened and flattened with the weld at the point of maximum bend (Fig. 27).

S9.1.3 *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. 28). 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.

S9.1.4 *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. 29 are recommended for use in making this test.

S9.1.5 *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. 30 (*a*) or a 60 deg included angle as shown in Fig. 30 (*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.

S9.1.6 *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 deg 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 deg around a mandrel having a diameter 8 times the nominal diameter of the pipe.

S9.1.7 *Transverse Guided Bend Test of Welds*—This bend test is used to determine the ductility of fusion welds. The specimens used are approximately $1^1/_2$ 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. 31(*a*) for face and root bend tests and in accordance with Fig. 31(*b*) for side bend tests. The dimensions of the plunger shall be as shown in Fig. 32 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.

S9.1.7.1 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.

III. STEEL FASTENERS

S10. Scope

S10.1 This supplement covers definitions and methods of testing peculiar to steel fasteners which are not covered in the general section of Methods A 370. Standard tests required by the individual product specifications are to be performed as outlined in the general section of these methods.

S10.2 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.

S11. Tension Tests

S11.1 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 S11.1.1 through S11.1.3 apply when testing bolts full size. Section S11.1.4 shall apply where the individual product specifications permit the use of machined specimens.

S11.1.1 *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.

S11.1.2 *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.

S11.1.2.1 *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 S11.1.4, 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).

S11.1.3 *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.

S11.1.3.1 *Method 2, Yield Strength*—The bolt shall be assembled in the testing equipment as outlined in S11.1.4. 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.

S11.1.4 *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. 33), 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:

$$A_s = 0.7854\ (D - (0.9743)/n)^2$$

where:

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

S11.1.5 *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 S11.1.4, except that a 10-deg wedge shall be placed under the same bolt previously tested for the proof load (see S11.1.1). 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. 34). The wedge shall have an included angle of 10 deg 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)
1/4 to 1/2	0.030 (0.76)	0.030 (0.76)
9/16 to 3/4	0.050 (1.3)	0.060 (1.5)
7/8 to 1	0.063 (1.5)	0.060 (1.5)
1 1/8 to 1 1/4	0.063 (1.5)	0.125 (3.2)
1 3/8 to 1 1/2	0.094 (2.4)	0.125 (3.2)

S11.1.6 *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 deg for sizes ¼ through ¾ in. (6.35 to 19.0 mm) and 4 deg for sizes over ¾ in.

S11.1.7 *Tension Testing of Bolts Machined to Round Test Specimens:*

S11.1.7.1 Bolts under 1½ in. (38 mm) in diameter which require machined tests shall use a standard ½-in., (13 mm) round 2-in. (51-mm) gage length test specimen, turned concentric with the axis of the bolt, leaving the head and threaded section intact as in Fig. 35. Bolts of small cross-section which will not permit taking this standard test specimen shall have a turned section as large as feasible and concentric with the axis of the bolt. The gage length for measuring the elongation shall be four times the diameter of the specimen. Figure 36 illustrates examples of these small size specimens.

S11.1.7.2 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. 37.

S11.1.7.3 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 methods, A 370.

S12. Speed of Testing

S12.1 Speed of testing shall be as prescribed in the individual product specifications.

S13. Hardness Tests for Bolts

S13.1 When specified, the bolts shall meet a hardness test. The Brinell or Rockwell hardness test is usually taken on the side or top of the bolt head. For final arbitration the hardness shall be taken on a transverse section through the threaded section of the bolt at a point one-quarter of the nominal diameter from the axis of the bolt. This section shall be taken at a distance from the end of the bolt which is equivalent to the diameter of the bolt. Due to possible distortion from the Brinell load, care shall be taken to see that this test meets all the provisions of 17.2 of the general section of these methods. Where the Brinell hardness test is impractical, the Rockwell hardness test shall be substituted. Rockwell hardness test procedures shall conform to Section 18 of these methods.

S14. Testing of Nuts

S14.1 *Proof Load*—A sample nut shall be assembled on a hardened threaded mandrel or on a bolt conforming to the particular specification. A load axial with the mandrel or bolt and equal to the specified proof load of the nut shall be applied. The nut shall resist this load without stripping or rupture. If the threads of the mandrel are damaged during the test the individual test shall be discarded. The mandrel shall be threaded to American National Standard Class 3 tolerance, except that the major diameter shall be the minimum major diameter with a tolerance of +0.002 in. (0.051 mm).

S14.2 *Hardness Test*—Rockwell hardness of nuts shall be determined on the top or bottom face of the nut. Brinell hardness shall be determined on the side of the nuts. Either method may be used at the option of the manufacturer, taking into account the size and grade of the nuts under test. When the standard Brinell hardness test results in deforming the nut it will be necessary to use a minor load or substitute a Rockwell hardness test.

S15. Bars Heat Treated or Cold Drawn for Use in the Manufacture of Studs, Nuts or Other Bolting Material

S15.1 When the bars as received by the manufacturer have been processed and proved to meet certain specified properties, it is not necessary to test the finished product when these properties have not been changed by the process of manufacture employed for the finished product.

IV. ROUND WIRE PRODUCTS

S16. Scope

S16.1 This supplement covers the apparatus, specimens and methods of testing peculiar to steel wire products which are not covered in the general section of Methods A 370.

S17. Apparatus

S17.1 *Gripping Devices*—Grips of either the wedge or snubbing types as shown in Figs. 38 and 39 shall be used (Note 14). When using grips of either type, care shall be taken that the axis of the test specimen is located approximately at the center line of the head of the testing machine (Note 15). When using wedge grips the liners used behind the grips shall be of the proper thickness.

NOTE 14—Testing machines usually are equipped with wedge grips. These wedge grips, irrespective of the type of testing machine, may be referred to as the "usual type" of wedge grips. The usual type of wedge grips generally furnish a satisfactory means of gripping wire. For tests of specimens of wire which are liable to be cut at the edges by the "usual type" of wedge grips, the snubbing type gripping device has proved satisfactory.

For testing round wire, the use of cylindrical seat in the wedge gripping device is optional.

NOTE 15—Any defect in a testing machine which may cause nonaxial application of load should be corrected.

S17.2 *Pointed Micrometer*—A micrometer with a pointed spindle and anvil suitable for reading the dimensions of the wire specimen at the fractured ends to the nearest 0.001 in. (0.025 mm) after breaking the specimen in the testing machine shall be used.

S18. Test Specimens

S18.1 Test specimens having the full cross-sectional area of the wire they represent shall be used. The standard gage length of the specimens shall be 10 in. (254 mm). However, if the determination of elongation values is not required, any convenient gage length is permissible. The total length of the specimens shall be at least equal to the gage length (10 in.) plus twice the length of wire required for the full use of the grip employed. For example, depending upon the type of testing machine and grips used, the minimum total length of specimen may vary from 14 to 24 in. (360 to 610 mm) for a 10-in. gage length specimen.

S18.2 Any specimen breaking in the grips shall be discarded and a new specimen tested.

S19. Elongation

S19.1 In determining permanent elongation, the ends of the fractured specimen shall be carefully fitted together and the distance between the gage marks measured to the nearest 0.01 in. (0.25 mm) with dividers and scale or other suitable device. The elongation is the increase in length of the gage length, expressed as a percentage of the original gage length. In reporting elongation values, both the percentage increase and the original gage length shall be given.

S19.2 In determining total elongation (elastic plus plastic extension) autographic or extensometer methods may be employed.

S19.3 If fracture takes place outside of the middle third of the gage length, the elongation value obtained may not be representative of the material.

S20. Reduction of Area

S20.1 The ends of the fractured specimen shall be carefully fitted together and the dimensions of the smallest cross section measured to the nearest 0.001 in. (0.025 mm) with a pointed micrometer. 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.

S20.2 The reduction of area test is not recommended in wire diameters less than 0.092 in. (2.34 mm) due to the difficulties of measuring the reduced cross sections.

S21. Rockwell Hardness Test

S21.1 With the exception of heat treated wire of diameter 0.100 in. (2.54 mm) and larger, the Rockwell hardness test is not recommended for round wire. On such heat-treated wire the specimen shall be flattened on two parallel sides by grinding. For round wire the tensile strength test is greatly to be preferred to the Rockwell hardness test.

S22. Wrapping Test

S22.1 This test, also referred to as a coiling test or as a wrap-around bend test, is sometimes used as a means for testing the ductility of certain kinds of wire. The wrapping may be done by any hand or power device that will coil the wire closely about a mandrel of the specified diameter for a required number of turns without damage to the wire surface. The sample shall be considered to have failed if any cracks occur in the wire after the first complete turn. The test shall be repeated if a crack occurs in the first turn since the wire may have been bent locally to a radius less than that specified.

S22.2 When the wrapping test is used to determine the adherence of coating for coated wires, the mandrel diameter is commonly larger than that used in the test when used as a measure of ductility.

V. NOTES ON SIGNIFICANCE OF NOTCHED-BAR IMPACT TESTING

S23. Notch Behavior

S23.1 The Charpy and Izod type tests bring out notch behavior (brittleness versus ductility) by applying a single overload of stress. The energy values determined are quantitative comparisons on a selected specimen but cannot be converted into energy values that would serve for engineering design calculations. The notch behavior indicated in an individual test applies only to the specimen size, notch geometry, and testing conditions involved and cannot be generalized to other sizes of specimens and conditions.

S23.2 The notch behavior of the face-centered cubic metals and alloys, a large group of nonferrous materials and the austenitic steels can be judged from their common tensile properties. If they are brittle in tension they will be brittle when notched, while if they are ductile in tension, they will be ductile when notched, except for unusually sharp or deep notches (much more severe than the standard Charpy or Izod specimens). Even low temperatures do not alter this characteristic of these materials. In contrast, the behavior of the ferritic steels under notch conditions cannot be predicted from their properties as revealed by the tension test. For the study of these materials the Charpy and Izod type tests are accordingly very useful. Some metals that display normal ductility in the tension test may nevertheless break in brittle fashion when tested or when used in the notched condition. Notched conditions include restraints to deformation in directions perpendicular to the major stress, or multiaxial stresses, and stress concentrations. It is in this field that the Charpy and Izod tests prove useful for determining the susceptibility of a steel to notch-brittle behavior though they cannot be directly used to appraise the serviceability of a structure.

S23.3 The testing machine itself must be sufficiently rigid or tests on high-strength low-energy materials will result in excessive elastic energy losses either upward through the pendulum shaft or downward through the base of the machine. If the anvil supports, the pendulum striking edge, or the machine foundation bolts are not securely fastened, tests on ductile materials in the range of 80 ft·lbf (108 J) may actually indicate values in excess of 90 to 100 ft·lbf (122 to 136 J).

S24. Notch Effect

S24.1 The notch results in a combination of multiaxial stresses associated with restraints to deformation in directions perpendicular to the major stress, and a stress concentration at the base of the notch. A severely notched condition is generally not desirable, and it becomes of real concern in those cases in which it initiates a sudden and complete failure of the brittle type. Some metals can be deformed in a ductile manner even down to the low temperatures of liquid air, while others may crack. This difference in behavior can be best understood by considering the cohesive strength of a material (or the property that holds it together) and its relation to the yield point. In cases of brittle fracture, the cohesive strength is exceeded before significant plastic deformation occurs and the fracture appears crystalline. In cases of the ductile or shear type of failure, considerable deformation precedes the final fracture and the broken surface appears fibrous instead of crystalline. In intermediate cases the fracture comes after a moderate amount of deformation and is part crystalline and part fibrous in appearance.

S24.2 When a notched bar is loaded, there is a normal stress across the base of the notch which tends to initiate fracture. The property that keeps it from cleaving, or holds it together, is the "cohesive strength." The bar fractures when the normal stress exceeds the cohesive strength. When this occurs without the bar deforming it is the condition for brittle fracture.

S24.3 In testing, though not in service because of side effects, it happens more commonly that plastic deformation precedes fracture. In addition to the normal stress, the applied load also sets up shear stresses which are about 45 deg to the normal stress. The elastic behavior terminates as soon as the shear stress exceeds the shear strength of the material and deformation or plastic yielding sets in. This is the condition for ductile failure.

S24.4 This behavior, whether brittle or ductile, depends on whether the normal stress exceeds the cohesive strength before the shear stress exceeds the shear strength. Several important facts of notch behavior follow from this. If the notch is made sharper or more drastic, the normal stress at the root of the notch will be increased in relation to the shear stress and the bar will be more prone to brittle fracture (see Table 10). Also, as the speed of deformation increases, the shear strength increases and the likelihood of brittle fracture increases. On the other hand, by raising the temperature, leaving the notch and the speed of deformation the same, the shear strength is lowered and ductile behavior is promoted, leading to shear failure.

S24.5 Variations in notch dimensions will seriously affect the results of the tests. Tests on E4340 steel specimens[9] have shown the effect of dimensional variations on Charpy results (see Table 10).

S25. Size Effect

S25.1 Increasing either the width or the depth of the specimen tends to increase the volume of metal subject to distortion, and by this factor tends to increase the energy absorption when breaking the specimen. However, any increase in size, particularly in width, also tends to increase the degree of restraint and by tending to induce brittle fracture, may decrease the amount of energy absorbed. Where a standard-size specimen is on the verge of brittle fracture, this is particularly true, and a double-width specimen may actually require less energy for rupture than one of standard width.

S25.2 In studies of such effects where the size of the material precludes the use of the standard specimen, as for example when the material is $^1/_4$-in. plate, subsize specimens are necessarily used. Such specimens (see Fig. 6 of Method E 23) are based on the Type A specimen of Fig. 4 of Method E 23.

S25.3 General correlation between the energy values obtained with specimens of different size or shape is not feasible, but limited correlations may be established for specification purposes on the basis of special studies of particular materials and particular specimens. On the other hand, in a study of the relative effect of process variations, evaluation by use of some arbitrarily selected specimen with some chosen notch will in most instances place the methods in their proper order.

S26. Effects of Testing Conditions

S26.1 The testing conditions also affect the notch behavior. So pronounced is the effect of temperature on the behavior of steel when notched that comparisons are frequently made by examining specimen fractures and by plotting energy value and fracture appearance versus temperature from tests of notched bars at a series of temperatures. When the test temperature has been carried low enough to start cleavage fracture, there may be an extremely sharp drop in impact value or there may be a relatively gradual falling off toward the lower temperatures. This drop in energy value starts when a specimen begins to exhibit some crystalline appearance in the fracture. The transition temperature at which this embrittling effect takes place varies considerably with the size of the part or test specimen and with the notch geometry.

S26.2 Some of the many definitions of transition temperature currently being used are: (*1*) the lowest temperature at which the specimen exhibits 100 percent fibrous fracture, (*2*) the temperature where the fracture shows a 50 percent crystalline and a 50 percent fibrous appearance, (*3*) the temperature corresponding to the energy value 50 percent of the difference between values obtained at 100 percent and 0 percent fibrous fracture,

[9] Fahey, N. H., "Effects of Variables in Charpy Impact Testing," *Materials Research & Standards*, MTRSA Vol 1, No. 11, Nov., 1961, p. 872.

and (4) the temperature corresponding to a specific energy value.

S26.3 A problem peculiar to Charpy-type tests occurs when high-strength, low-energy specimens are tested at low temperatures. These specimens may not leave the machine in the direction of the pendulum swing but rather in a sidewise direction. To ensure that the broken halves of the specimens do not rebound off some component of the machine and contact the pendulum before it completes its swing, modifications may be necessary in older model machines. These modifications differ with machine design. Nevertheless the basic problem is the same in that provisions must be made to prevent rebounding of the fractured specimens into any part of the swinging pendulum. Where design permits, the broken specimens may be deflected out of the sides of the machine and yet in other designs it may be necessary to contain the broken specimens within a certain area until the pendulum passes through the anvils. Some low-energy high-strength steel specimens leave impact machines at speeds in excess of 50 ft (15.3 m)/s although they were struck by a pendulum traveling at speeds approximately 17 ft (5.2 m)/s. If the force exerted on the pendulum by the broken specimens is sufficient, the pendulum will slow down and erroneously high energy values will be recorded. This problem accounts for many of the inconsistencies in Charpy results reported by various investigators within the 10 to 25-ft·lbf (14 to 34 J) range. Section 5.5 of Methods E 23 discusses the two basic machine designs and a modification found to be satisfactory in minimizing jamming.

S27. Velocity of Straining

S27.1 Velocity of straining is likewise a variable that affects the notch behavior of steel. The impact test shows somewhat higher energy absorption values than the static tests above the transition temperature and yet, in some instances, the reverse is true below the transition temperature.

S28. Correlation with Service

S28.1 While Charpy or Izod tests may not directly predict the ductile or brittle behavior of steel as commonly used in large masses or as components of large structures, these tests can be used as acceptance tests of identity for different lots of the same steel or in choosing between different steels, when correlation with reliable service behavior has been established. It may be necessary to make the tests at properly chosen temperatures other than room temperature. In this, the service temperature or the transition temperature of full-scale specimens does not give the desired transition temperatures for Charpy or Izod tests since the size and notch geometry may be so different. Chemical analysis, tension, and hardness tests may not indicate the influence of some of the important processing factors that affect susceptibility to brittle fracture nor do they comprehend the effect of low temperatures in inducing brittle behavior.

VI. PROCEDURE FOR CONVERTING PERCENTAGE ELONGATION OF A STANDARD ROUND TENSION TEST SPECIMEN TO EQUIVALENT PERCENTAGE ELONGATION OF A STANDARD FLAT SPECIMEN

S29. Scope

S29.1 This method specifies a procedure for converting percentage elongation after fracture obtained in a standard 0.500-in. (12.7 mm) diameter by 2-in. (51-mm) gage length test specimen to standard flat test specimens $^1/_2$ in. by 2 in. and $1^1/_2$ in. by 8 in. (38.1 by 203 mm).

S30. Basic Equation

S30.1 The conversion data in this method are based on an equation by Bertella,[10] and used by Oliver[11] and others. The relationship between elongations in the standard 0.500-in. diameter by 2.0-in. test specimen and other standard specimens can be calculated as follows:

$$e = e_o\,(4.47\,\sqrt{A}/L)^a$$

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[10] Bertella, C. A., *Giornale del Genio Civile,* Vol 60, 1922, p. 343.

[11] Oliver, D. A., *Proceedings of Institute of Mechanical Engineers,* Vol 11, 1928, p. 827.

where:

e_o = percentage elongation after fracture on a standard test specimen having a 2-in. gage length and 0.500-in. diameter,

e = percentage elongation after fracture on a standard test specimen having a gage length L and a cross-sectional area A, and

a = constant characteristic of the test material.

S31. Application

S31.1 In applying the above equation the constant a is characteristic of the test material. The value $a = 0.4$ has been found to give satisfactory conversions for carbon, carbon-manganese, molybdenum, and chromium-molybdenum steels within the tensile strength range of 40,000 to 85,000 psi (275 to 585 MPa) and in the hot-rolled, in the hot-rolled and normalized, or in the annealed condition, with or without tempering. Note that the cold reduced and quenched and tempered states are excluded. For annealed austenitic stainless steels, the value $a = 0.127$ has been found to give satisfactory conversions.

S31.2 Table 11 has been calculated taking $a = 0.4$, with the standard 0.500-in. (12.7 mm) diameter by 2-in. (51 mm) gage length test specimen as the reference specimen. In the case of the subsize specimens 0.350 in. (8.89 mm) in diameter by 1.4 in. (35.6 mm) gage length, and 0.250 (6.35 mm) diameter by 1.0 in. (25.4 mm) gage length the factor in the equation is 4.51 instead of 4.37. The small error introduced by using Table 11 for the subsized specimens may be neglected. Table 12 for annealed austenitic steels has been calculated taking $a = 0.127$, with the standard 0.500-in. diameter by 2-in. gage length test specimen as the reference specimen.

S31.3 Elongation given for a standard 0.500-in. diameter by 2-in. gage length specimen may be converted to elongation for $^1/_2$ in. by 2 in. or $1^1/_2$ in. by 8 in. (38.1 by 203 mm) flat specimens by multiplying by the indicated factor in Tables 11 and 12.

S31.4 These elongation conversions shall not be used where the width to thickness ratio of the test piece exceeds 20, as in sheet specimens under 0.025 in. (0.635 mm) in thickness.

S31.5 While the conversions are considered to be reliable within the stated limitations and may generally be used in specification writing where it is desirable to show equivalent elongation requirements for the several standard ASTM tension specimens covered in Methods A 370, consideration must be given to the metallurgical effects dependent on the thickness of the material as processed.

VII. METHOD OF TESTING UNCOATED SEVEN-WIRE STRESS-RELIEVED STRAND FOR PRESTRESSED CONCRETE

S32. Scope

S32.1 This method provides procedures for the tension testing of uncoated seven-wire stress-relieved strand for prestressed concrete. This method is intended for use in evaluating the strand for the properties prescribed in Specification A 416.

S33. General Precautions

S33.1 Premature failure of the test specimens may result if there is any appreciable notching, cutting, or bending of the specimen by the gripping devices of the testing machine.

S33.2 Errors in testing may result if the seven wires constituting the strand are not loaded uniformly.

S33.3 The mechanical properties of the strand may be materially affected by excessive heating during specimen preparation.

S33.4 These difficulties may be minimized by following the suggested methods of gripping described in Section S35.

S34. Gripping Devices

S34.1 The true mechanical properties of the strand are determined by a test in which fracture of the specimen occurs in the free span between the jaws of the testing machine. Therefore, it is desirable to establish a test procedure with suitable apparatus which will consistently produce such results. Due to inherent physical characteristics of individual machines, it is not practical to recommend a universal gripping procedure that is suitable for all testing machines. Therefore, it is necessary to determine which of the methods of gripping described in S34.2 to S34.8 is most suitable for the testing equipment available.

S34.2 *Standard V-Grips with Serrated Teeth* (*Note 16*).

S34.3 *Standard V-Grips with Serrated Teeth* (*Note 16*), *Using Cushioning Material*—In this method, some material is placed between the grips and the specimen to minimize the notching effect of the teeth. Among the materials which have been used are lead foil, aluminum foil, carborundum cloth, bra shims, etc. The type and thickness of material required is dependent on the shape, condition, and coarseness of the teeth.

S34.4 *Standard V-Grips with Serrated Teeth* (*Note 16*), *Using Special Preparation of the Gripped Portions of the Specimen*—One of the methods used is tinning, in which the gripped portions are cleaned, fluxed, and coated by multiple dips in molten tin alloy held just above the melting point. Another method of preparation is encasing the gripped portions in metal tubing or flexible conduit, using epoxy resin as the bonding agent. The encased portion should be approximately twice the length of lay of the strand.

S34.5 *Special Grips with Smooth, Semi-Cylindrical Grooves* (*Note 17*)—The grooves and the gripped portions of the specimen are coated with an abrasive slurry which holds the specimen in the smooth grooves, preventing slippage. The slurry consists of abrasive such as Grade 3-F aluminum oxide and a carrier such as water or glycerin.

S34.6 *Standard Sockets of the Type Used for Wire Rope*—The gripped portions of the specimen are anchored in the sockets with zinc. The special procedures for socketing usually employed in the wire rope industry must be followed.

S34.7 *Dead-End Eye Splices*—These devices are available in sizes designed to fit each size of strand to be tested.

S34.8 *Chucking Devices*—Use of chucking devices of the type generally employed for applying tension to strands in casting beds is not recommended for testing purposes.

NOTE 16—The number of teeth should be approximately 15 to 30 per in., and the minimum effective gripping length should be approximately 4 in. (102 mm).

NOTE 17—The radius of curvature of the grooves is approximately the same as the radius of the strand being tested, and is located 1/32 in. (0.79 mm) above the flat face of the grip. This prevents the two grips from closing tightly when the specimen is in place.

S35. Specimen Preparation

S35.1 Nonuniform loading of the seven wires in the strand may result if slippage of the individual wires of the strand, either the outside wire or the center wire, occur during the tension test. Wire slippage may be minimized by fusing together the cut ends of the specimen. This fusing can be concurrent with torch cutting of the specimens.

S35.2 If the molten-metal temperatures employed during hot-dip tinning or socketing with metallic material are too high, over approximately 700 F (370 C), the specimen may be heat affected with a subsequent loss of strength and ductility. Careful temperature controls should be maintained if such methods of specimen preparation are used.

S36. Procedure

S36.1 *Yield Strength*—For determining the yield strength use a Class B-1 extensometer (Note 18) as described in Method E 83. Apply an initial load of 10 percent of the expected minimum breaking strength to the specimen, then attach the extensometer and adjust it to a reading of 0.001 in./in. of gage length. Then increase the load until the extensometer indicates an extension of 1 percent. Record the load for this extension as the yield strength. The extensometer may be removed from the specimen after the yield strength has been determined.

S36.2 *Elongation*—For determining the elongation use a Class D extensometer (Note 18), as described in Method E 83, having a gage length of not less than 24 in. (610 mm) (Note 19). Apply an initial load of 10 percent of the required minimum breaking strength to the specimen, then attach the extensometer (Note 18) and adjust it to a zero reading. The extensometer may be removed from the specimen prior to rupture after the specified minimum elongation has been exceeded. It is not necessary to determine the final elongation value.

S36.3 *Breaking Strength*—Determine the maximum load at which one or more wires of the strand are fractured. Record this load as the breaking strength of the strand.

NOTE 18—The yield-strength extensometer and the elongation extensometer may be the same instrument or two separate instruments. Two separate instruments are advisable since the more sensitive yield-strength extensometer, which could be damaged when the strand fractures, may be removed following the determination of yield strength. The elongation extensometer may be constructed with less sensitive parts or be constructed in such a way that little damage would result if fracture occurs while the extensometer is attached to the specimen.

NOTE 19—Specimens that break outside the extensometer or in the jaws and yet meet the minimum specified values are considered as meeting the mechanical property requirements of the product Specification A 416, regardless of what procedure of gripping has been used. Specimens that break outside of the extensometer or in the jaws and do not meet the minimum specified values are subject to retest in accordance with Specification A 416. Specimens that break between the jaws of the extensometer and do not meet the minimum specified values are subject to retest as provided in Section 14 of Specification A 416.

VIII. ROUNDING OF TEST DATA

S37. Rounding

S37.1 Recommended levels for rounding reported values of test data are given in Table 13. These values are designed to provide uniformity in reporting and data storage, and should be used in all cases except where they conflict with specific requirements of a product specification.

TABLE 1 Details of Test Coupon Design for Casting (See Fig. 3)

NOTE 1—*Test Coupons for Large and Heavy Steel Castings:* The test coupons in Fig. 3 are to be used for large and heavy steel castings. However, at the option of the foundry the cross-sectional area and length of the standard coupon may be increased as desired. This provision does not apply to ASTM Specification A 356, for Heavy-Walled Carbon and Low Alloy Steel Castings for Steam Turbines (*Annual Book of ASTM Standards*, Vol 01.02).

NOTE 2—*Bend Bar:* If a bend bar is required, an alternate design (as shown by dotted lines in Fig. 3) is indicated.

Leg Design (125mm)		Riser Design	
1. *L* (length)	A 5 in. (125 mm) minimum length will be used. This length may be increased at the option of the foundry to accommodate additional test bars (see Note 1).	1. *L* (length)	The length of the riser at the base will be the same as the top length of the leg. The length of the riser at the top therefore depends on the amount of taper added to the riser.
2. End taper	Use of and size of end taper is at the option of the foundry.	2. Width	The width of the riser at the base of a multiple-leg coupon shall be *n* (2¼) (57 mm) − ⅝ (16 mm) where *n* equals the number of legs attached to the coupon. The width of the riser at the top is therefore dependent on the amount of taper added to the riser.
3. Height	1¼ in. (32 mm)		
4. Width (at top)	1¼ in. (32 mm) (see Note 1).		
5. Radius (at bottom)	½ in. (13 mm), max		
6. Spacing between legs	A ½-in. (13-mm) radius will be used between the legs.		
7. Location of test bars	The tensile, bend, and impact bars will be taken from the lower portion of the leg (see Note 2).		
8. Number of legs	The number of legs attached to the coupon is at the option of the foundry providing they are equispaced according to Item 6.	3. *T* (riser taper)	Use of and size is at the option of the foundry.
		Height	The minimum height of the riser shall be 2 in. (51 mm). The maximum height is at the option of the foundry for the following reasons: (*a*) Many risers are cast open, (*b*) different compositions may require variation in risering for soundness, (*c*) different pouring temperatures may require variation in risering for soundness.
9. R_s	Radius from 0 to approximately 1/16 in. (2 mm).		

TABLE 2 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 Note 5 of Fig. 5.

TABLE 3A 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 Indentation Diameter, mm	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			Approximate Tensile Strength, ksi (MPa)
						15N Scale, 15-kgf Load, Diamond Penetrator	30N Scale 30-kgf Load, Diamond Penetrator	45N Scale, 45-kgf Load, Diamond Penetrator	
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	2.26	739	846	83.9	92.2	81.9	72.0	...
64	800	2.28	722	822	83.4	91.8	81.1	71.0	...
63	772	2.31	706	799	82.8	91.4	80.1	69.9	...
62	746	2.34	688	776	82.3	91.1	79.3	68.8	...
61	720	2.37	670	754	81.8	90.7	78.4	67.7	...
60	697	2.40	654	732	81.2	90.2	77.5	66.6	...
59	674	2.44	634	710	80.7	89.8	76.6	65.5	351 (2420)
58	653	2.47	615	690	80.1	89.3	75.7	64.3	338 (2330)
57	633	2.51	595	670	79.6	88.9	74.8	63.2	325 (2240)
56	613	2.55	577	650	79.0	88.3	73.9	62.0	313 (2160)
55	595	2.59	560	630	78.5	87.9	73.0	60.9	301 (2070)
54	577	2.63	543	612	78.0	87.4	72.0	59.8	292 (2010)
53	560	2.67	525	594	77.4	86.9	71.2	58.6	283 (1950)
52	544	2.70	512	576	76.8	86.4	70.2	57.4	273 (1880)
51	528	2.75	496	558	76.3	85.9	69.4	56.1	264 (1820)
50	513	2.79	482	542	75.9	85.5	68.5	55.0	255 (1760)
49	498	2.83	468	526	75.2	85.0	67.6	53.8	246 (1700)
48	484	2.87	455	510	74.7	84.5	66.7	52.5	238 (1640)
47	471	2.91	442	495	74.1	83.9	65.8	51.4	229 (1580)
46	458	2.94	432	480	73.6	83.5	64.8	50.3	221 (1520)
45	446	2.98	421	466	73.1	83.0	64.0	49.0	215 (1480)
44	434	3.02	409	452	72.5	82.5	63.1	47.8	208 (1430)
43	423	3.05	400	438	72.0	82.0	62.2	46.7	201 (1390)
42	412	3.09	390	426	71.5	81.5	61.3	45.5	194 (1340)
41	402	3.13	381	414	70.9	80.9	60.4	44.3	188 (1300)
40	392	3.17	371	402	70.4	80.4	59.5	43.1	182 (1250)
39	382	3.21	362	391	69.9	79.9	58.6	41.9	177 (1220)
38	372	3.24	353	380	69.4	79.4	57.7	40.8	171 (1180)
37	363	3.28	344	370	68.9	78.8	56.8	39.6	166 (1140)
36	354	3.32	336	360	68.4	78.3	55.9	38.4	161 (1110)
35	345	3.36	327	351	67.9	77.7	55.0	37.2	156 (1080)
34	336	3.41	319	342	67.4	77.2	54.2	36.1	152 (1050)
33	327	3.45	311	334	66.8	76.6	53.3	34.9	149 (1030)
32	318	3.50	301	326	66.3	76.1	52.1	33.7	146 (1010)
31	310	3.54	294	318	65.8	75.6	51.3	32.5	141 (970)

TABLE 3A—*Continued*

Rockwell C Scale, 150-kgf Load, Diamond Penetrator	Vickers Hardness Number	Brinell Indentation Diameter, mm	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			Approximate Tensile Strength, ksi (MPa)
						15N Scale, 15-kgf Load, Diamond Penetrator	30N Scale 30-kgf Load, Diamond Penetrator	45N Scale, 45-kgf Load, Diamond Penetrator	
30	302	3.59	286	311	65.3	75.0	50.4	31.3	138 (950)
29	294	3.64	279	304	64.6	74.5	49.5	30.1	135 (930)
28	286	3.69	271	297	64.3	73.9	48.6	28.9	131 (900)
27	279	3.73	264	290	63.8	73.3	47.7	27.8	128 (880)
26	272	3.77	258	284	63.3	72.8	46.8	26.7	125 (860)
25	266	3.81	253	278	62.8	72.2	45.9	25.5	123 (850)
24	260	3.86	247	272	62.4	71.6	45.0	24.3	119 (820)
23	254	3.89	243	266	62.0	71.0	44.0	23.1	117 (810)
22	248	3.93	237	261	61.5	70.5	43.2	22.0	115 (790)
21	243	3.98	231	256	61.0	69.9	42.3	20.7	112 (770)
20	238	4.02	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. Where more precise conversions are required, they should be developed specially for each steel composition, heat treatment, and part.

TABLE 3B Approximate Hardness Conversion Numbers for Nonaustenitic Steels[4] (Rockwell B to other Hardness Numbers)

Rockwell B Scale, 100-kgf Load 1/16-in. (1.588-mm) Ball	Vickers Hardness Number	Brinell Indentation Diameter, mm	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	3.91	240	251	61.5	...	93.1	83.1	72.9	116 (800)
99	234	3.96	234	246	60.9	...	92.8	82.5	71.9	114 (785)
98	228	4.01	228	241	60.2	...	92.5	81.8	70.9	109 (750)
97	222	4.06	222	236	59.5	...	92.1	81.1	69.9	104 (715)
96	216	4.11	216	231	58.9	...	91.8	80.4	68.9	102 (705)
95	210	4.17	210	226	58.3	...	91.5	79.8	67.9	100 (690)
94	205	4.21	205	221	57.6	...	91.2	79.1	66.9	98 (675)
93	200	4.26	200	216	57.0	...	90.8	78.4	65.9	94 (650)
92	195	4.32	195	211	56.4	...	90.5	77.8	64.8	92 (635)
91	190	4.37	190	206	55.8	...	90.2	77.1	63.8	90 (620)
90	185	4.43	185	201	55.2	...	89.9	76.4	62.8	89 (615)
89	180	4.48	180	196	54.6	...	89.5	75.8	61.8	88 (605)
88	176	4.53	176	192	54.0	...	89.2	75.1	60.8	86 (590)
87	172	4.58	172	188	53.4	...	88.9	74.4	59.8	84 (580)
86	169	4.62	169	184	52.8	...	88.6	73.8	58.8	83 (570)
85	165	4.67	165	180	52.3	...	88.2	73.1	57.8	82 (565)
84	162	4.71	162	176	51.7	...	87.9	72.4	56.8	81 (560)
83	159	4.75	159	173	51.1	...	87.6	71.8	55.8	80 (550)
82	156	4.79	156	170	50.6	...	87.3	71.1	54.8	77 (530)
81	153	4.84	153	167	50.0	...	86.9	70.4	53.8	73 (505)
80	150	4.88	150	164	49.5	...	86.6	69.7	52.8	72 (495)
79	147	4.93	147	161	48.9	...	86.3	69.1	51.8	70 (485)
78	144	4.98	144	158	48.4	...	86.0	68.4	50.8	69 (475)
77	141	5.02	141	155	47.9	...	85.6	67.7	49.8	68 (470)
76	139	5.06	139	152	47.3	...	85.3	67.1	48.8	67 (460)
75	137	5.10	137	150	46.8	99.6	85.0	66.4	47.8	66 (455)
74	135	5.13	135	147	46.3	99.1	84.7	65.7	46.8	65 (450)
73	132	51.8	132	145	45.8	98.5	84.3	65.1	45.8	64 (440)
72	130	5.22	130	143	45.3	98.0	84.0	64.4	44.8	63 (435)
71	127	5.27	127	141	44.8	97.4	83.7	63.7	43.8	62 (425)
70	125	5.32	125	139	44.3	96.8	83.4	63.1	42.8	61 (420)
69	123	5.36	123	137	43.8	96.2	83.0	62.4	41.8	60 (415)
68	121	5.40	121	135	43.3	95.6	82.7	61.7	40.8	59 (405)
67	119	5.44	119	133	42.8	95.1	82.4	61.0	39.8	58 (400)
66	117	5.48	117	131	42.3	94.5	82.1	60.4	38.7	57 (395)
65	116	5.51	116	129	41.8	93.9	81.8	59.7	37.7	56 (385)
64	114	5.54	114	127	41.4	93.4	81.4	59.0	36.7	...
63	112	5.58	112	125	40.9	92.8	81.1	58.4	35.7	...

TABLE 3B *Continued*

Rockwell B Scale, 100-kgf Load 1/16-in. (1.588-mm) Ball	Vickers Hardness Number	Brinell Indentation Diameter, mm	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			Approximate Tensile Strength ksi (MPa)
							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	
62	110	5.63	110	124	40.4	92.2	80.8	57.7	34.7	...
61	108	5.68	108	122	40.0	91.7	80.5	57.0	33.7	...
60	107	5.70	107	120	39.5	91.1	80.1	56.4	32.7	...
59	106	5.73	106	118	39.0	90.5	79.8	55.7	31.7	...
58	104	5.77	104	117	38.6	90.0	79.5	55.0	30.7	...
57	103	5.81	103	115	38.1	89.4	79.2	54.4	29.7	...
56	101	5.85	101	114	37.7	88.8	78.8	53.7	28.7	...
55	100	5.87	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	86.5	77.9	51.7	25.7	...
52	...	...	...	109	35.9	86.0	77.5	51.0	24.7	...
51	...	...	...	108	35.5	85.4	77.2	50.3	23.7	...
50	...	...	...	107	35.0	84.8	76.9	49.7	22.7	...
49	...	...	...	106	34.6	84.3	76.6	49.0	21.7	...
48	...	...	...	105	34.1	83.7	76.2	48.3	20.7	...
47	...	...	...	104	33.7	83.1	75.9	47.7	19.7	...
46	...	...	...	103	33.3		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	...
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. Where more precise conversions are required, they should be developed specially for each steel composition, heat treatment, and part.

TABLE 3C 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

TABLE 3D 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

TABLE 4 Percent Shear for Measurements Made in Inches

NOTE—Since Table 4 is set up for finite measurements or dimensions *A* and *B*, 100 percent 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 5 Percent Shear for Measurements Made in Millimeters

NOTE—Since Table 5 is set up for finite measurements or dimensions *A* and *B*, 100 percent 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	96	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

TABLE 6 Recommended Practice for Selecting Bend Test Specimens

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).

Flats		
Thickness, in. (mm)	Width, in. (mm)	Recommended Size
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.

Rounds, Squares, Hexagons, and Octagons	
Diameter or Distance Between Parallel Faces, in. (mm)	Recommended Size
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.

TABLE 7 Recommendations for Selecting Tension Test Specimens

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 5/8 (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 percent 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.
5/8 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 percent 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).

Rounds, Squares, Hexagons, and Octagons

Diameter or Distance Between Parallel Faces, in. (mm)	Hot-Rolled Bars	Cold-Finished Bars
Under 5/8	Full section by 8-in. (203-mm) gage length or machine to sub-size specimen (Fig. 5).	Machine to sub-size specimen (Fig. 5).
5/8 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 percent less than test specimen width.

TABLE 8 Wall Thickness Limitations of Superficial Hardness Test on Annealed or Ductile Materials[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 9 Wall Thickness Limitations of Superficial Hardness Test on Cold Worked or Heat Treated Material[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.

TABLE 10 Effect of Varying Notch Dimensions on Standard Specimens

	High-Energy Specimens, ft·lbf (J)	High-Energy Specimens, ft·lbf (J)	Low-Energy Specimens, ft·lbf (J)
Specimen with standard dimensions	76.0 ± 3.8 (103.0 ± 5.2)	44.5 ± 2.2 (60.3 ± 3.0)	12.5 ± 1.0 (16.9 ± 1.4)
Depth of notch, 0.084 in. (2.13 mm)[a]	72.2 (97.9)	41.3 (56.0)	11.4 (15.5)
Depth of notch, 0.0805 in. (2.04 mm)[a]	75.1 (101.8)	42.2 (57.2)	12.4 (16.8)
Depth of notch, 0.0775 in. (1.77 mm)[a]	76.8 (104.1)	45.3 (61.4)	12.7 (17.2)
Depth of notch, 0.074 in. (1.57 mm)[a]	79.6 (107.9)	46.0 (62.4)	12.8 (17.3)
Radius at base of notch, 0.005 in. (0.127 mm)[b]	72.3 (98.0)	41.7 (56.5)	10.8 (14.6)
Radius at base of notch, 0.015 in. (0.381 mm)[b]	80.0 (108.5)	47.4 (64.3)	15.8 (21.4)

[a] Standard 0.079 ± 0.002 in. (2.00 ± 0.05 mm).
[b] Standard 0.010 ± 0.001 in. (0.25 ± 0.025 mm).

TABLE 11 Carbon and Alloy Steels—Material Constant a = 0.4. Multiplication Factors for Converting Percent Elongation from ½-in. Diameter by 2-in. Gage Length Standard Tension Test Specimen to Standard ½ by 2-in. and 1½ by 8-in. Flat Specimens

Thickness, in.	½ by 2-in. Specimen	1½ by 8-in. Specimen	Thickness, in.	1½ by 8-in. Specimen
0.025	0.574	...	0.800	0.822
0.030	0.596	...	0.850	0.832
0.035	0.614	...	0.900	0.841
0.040	0.631	...	0.950	0.850
0.045	0.646	...	1.000	0.859
0.050	0.660	...	1.125	0.880
0.055	0.672	...	1.250	0.898
0.060	0.684	...	1.375	0.916
0.065	0.695	...	1.500	0.932
0.070	0.706	...	1.625	0.947
0.075	0.715	...	1.750	0.961
0.080	0.725	...	1.875	0.974
0.085	0.733	...	2.000	0.987
0.090	0.742	0.531	2.125	0.999
0.100	0.758	0.542	2.250	1.010
0.110	0.772	0.553	2.375	1.021
0.120	0.786	0.562	2.500	1.032
0.130	0.799	0.571	2.625	1.042
0.140	0.810	0.580	2.750	1.052
0.150	0.821	0.588	2.875	1.061
0.160	0.832	0.596	3.000	1.070
0.170	0.843	0.603	3.125	1.079
0.180	0.852	0.610	3.250	1.088
0.190	0.862	0.616	3.375	1.096
0.200	0.870	0.623	3.500	1.104
0.225	0.891	0.638	3.625	1.112
0.250	0.910	0.651	3.750	1.119
0.275	0.928	0.664	3.875	1.127
0.300	0.944	0.675	4.000	1.134
0.325	0.959	0.686	...	...
0.350	0.973	0.696	...	...
0.375	0.987	0.706	...	...
0.400	1.000	0.715	...	...
0.425	1.012	0.724	...	...
0.450	1.024	0.732	...	...
0.475	1.035	0.740	...	...
0.500	1.045	0.748	...	...
0.525	1.056	0.755	...	...
0.550	1.066	0.762	...	...
0.575	1.075	0.770	...	...
0.600	1.084	0.776	...	...
0.625	1.093	0.782	...	...
0.650	1.101	0.788	...	...
0.675	1.110	...	...	...
0.700	1.118	0.800	...	...
0.725	1.126	...	...	...
0.750	1.134	0.811	...	...

TABLE 12 Annealed Austenitic Stainless Steels—Material Constant a = 0.127. Multiplication Factors for Converting Percent Elongation from ½-in. Diameter by 2-in. Gage Length Standard Tension Test Specimen to Standard ½ by 2-in. and 1½ by 8-in. Flat Specimens

Thickness, in.	½ by 2-in. Specimen	1½ by 8-in. Specimen	Thickness, in.	1½ by 8-in. Specimen
0.025	0.839	...	0.800	0.940
0.030	0.848	...	0.850	0.943
0.035	0.857	...	0.900	0.947
0.040	0.864	...	0.950	0.950
0.045	0.870	...	1.000	0.953
0.050	0.876	...	1.125	0.960
0.055	0.882	...	1.250	0.966
0.060	0.886	...	1.375	0.972
0.065	0.891	...	1.500	0.978
0.070	0.895	...	1.625	0.983
0.075	0.899	...	1.750	0.987
0.080	0.903	...	1.875	0.992
0.085	0.906	...	2.000	0.996
0.090	0.909	0.818	2.125	1.000
0.095	0.913	0.821	2.250	1.003
0.100	0.916	0.823	2.375	1.007
0.110	0.921	0.828	2.500	1.010
0.120	0.926	0.833	2.625	1.013
0.130	0.931	0.837	2.750	1.016
0.140	0.935	0.841	2.875	1.019
0.150	0.940	0.845	3.000	1.022
0.160	0.943	0.848	3.125	1.024
0.170	0.947	0.852	3.250	1.027
0.180	0.950	0.855	3.375	1.029
0.190	0.954	0.858	3.500	1.032
0.200	0.957	0.860	3.625	1.034
0.225	0.964	0.867	3.750	1.036
0.250	0.970	0.873	3.875	1.038
0.275	0.976	0.878	4.000	1.041
0.300	0.982	0.883	...	...
0.325	0.987	0.887	...	...
0.350	0.991	0.892	...	...
0.375	0.996	0.895	...	...
0.400	1.000	0.899	...	...
0.425	1.004	0.903	...	...
0.450	1.007	0.906	...	...
0.475	1.011	0.909	...	...
0.500	1.014	0.912	...	...
0.525	1.017	0.915	...	...
0.550	1.020	0.917	...	...
0.575	1.023	0.920	...	...
0.600	1.026	0.922	...	...
0.625	1.029	0.925	...	...
0.650	1.031	0.927	...	...
0.675	1.034	...	...	...
0.700	1.036	0.932	...	...
0.725	1.038	...	...	...
0.750	1.041	0.936	...	...

TABLE 13 Recommended Values for Rounding Test Data

Test Quantity	Test Data Range	Rounded Value[A]
Yield Point, Yield Strength, Tensile Strength	up to 50 000 psi, excl	100 psi
	50 000 to 100 000 psi, excl	500 psi
	100 000 psi and above	1000 psi
	up to 500 MPa, excl	1 MPa
	500 to 1000 MPa, excl	5 MPa
	1000 MPa and above	10 MPa
Elongation	0 to 10 %, excl	0.5 %
	10 % and above	1 %
Reduction of Area	0 to 10 %, excl	0.5 %
	10 % and above	1 %
Impact Energy	0 to 240 ft·lbf (or 0 to 325 J)	1 ft·lbf (or 1 J)[B]
Brinell Hardness	all values	tabular value[C]
Rockwell Hardness	all scales	1 Rockwell Number

[A] Round test data to the nearest integral multiple of the values in this column. If the data value is exactly midway between two rounded values, round to the higher value.

[B] These units are not equivalent but the rounding occurs in the same numerical ranges for each. (1 ft·lbf = 1.356 J.)

[C] Round the mean diameter of the Brinell impression to the nearest 0.05 mm and report the corresponding Brinell hardness number read from the table without further rounding.

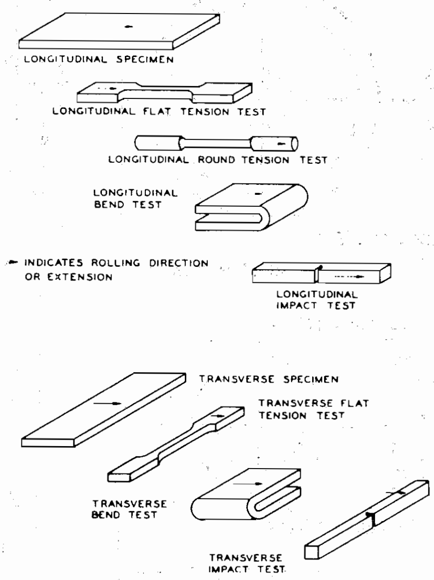
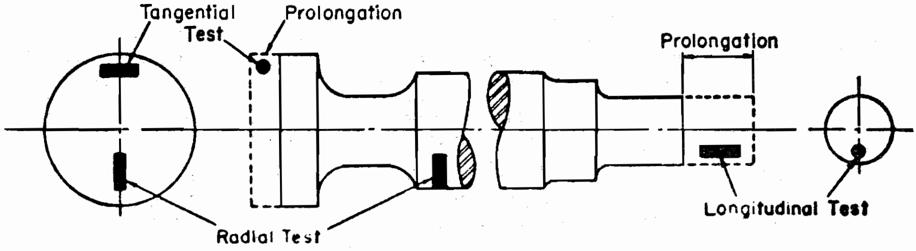
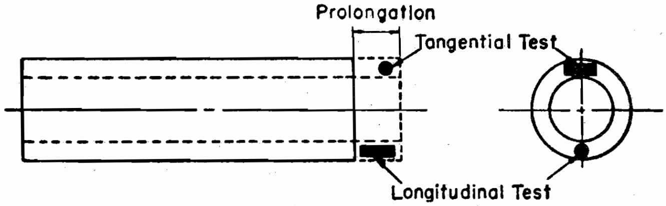


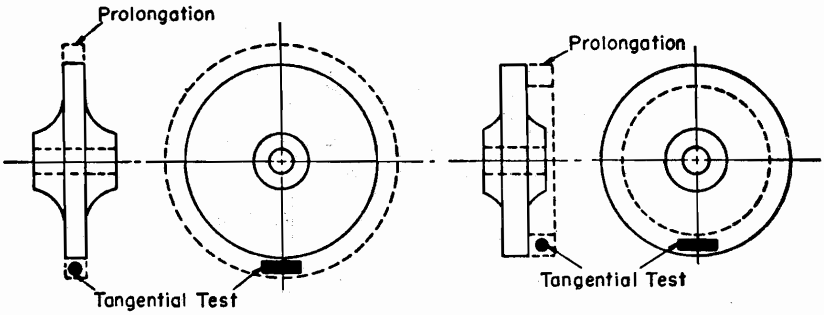
FIG. 1 The Relation of Test Coupons and Test Specimens to Rolling Direction or Extension (Applicable to General Wrought Products).



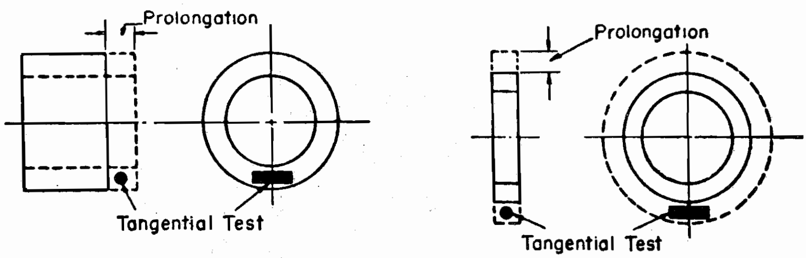
(*a*) **Shafts and Rotors**



(*b*) **Hollow Forgings.**

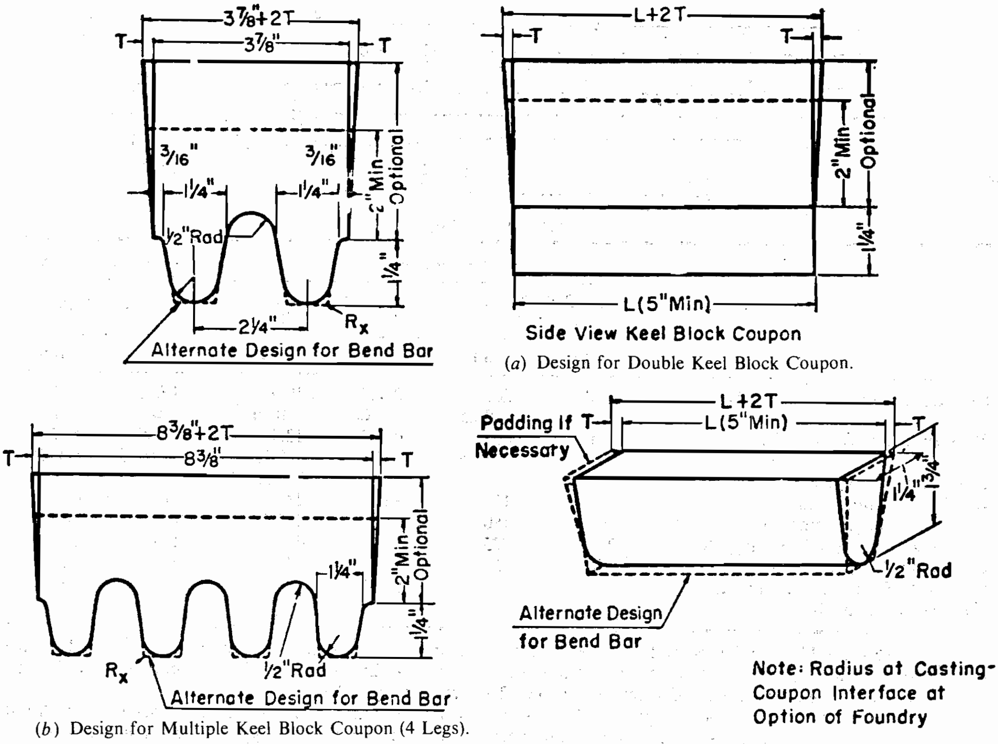


(*c*) **Disk Forgings**



(*d*) **Ring Forgings.**

FIG. 2 Locations of Test Specimens for Various Types of Forgings.



(a) Design for Double Keel Block Coupon.

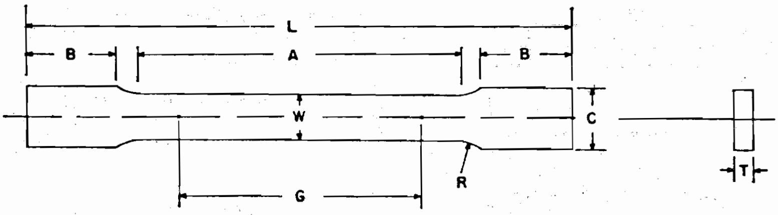
(b) Design for Multiple Keel Block Coupon (4 Legs).

(c) Design for "Attached" Coupon.

Metric Equivalents

in.	3/16	1/2	1 1/4	1 3/4	2	2 1/4	3 7/8	5	8 3/8
mm	4.8	13	32	45	51	57	98	127	213

FIG. 3 Test Coupons for Castings (see Table 1 for Details of Design).



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, 4, and 5)	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 6)			thickness of material			
R—Radius of fillet, min	½	13	½	13	¼	6
L—Over-all length, min (Notes 2 and 7)	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 8)	3	75	2	50	1¼	32
C—Width of grip section, approximate (Notes 4, 9, and 10)	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—When elongation measurements of 1½-in. (40-mm) wide specimens are not required, a gage length (*G*) of 2.000 in. ± 0.005 in. (50.0 mm ± 0.10 mm) with all other dimensions similar to the plate-type specimen 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 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 5—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 6—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.

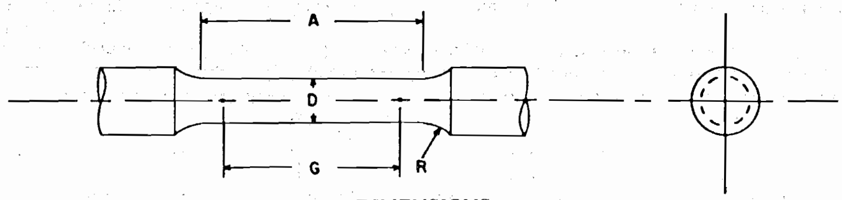
NOTE 7—To aid in obtaining axial loading during testing of ¼-in. (6-mm) wide specimens, the over-all length should be as the material will permit.

NOTE 8—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 9—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 10—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. 4 Rectangular Tension Test Specimens.



DIMENSIONS

Nominal Diameter	Standard Specimen in.	Standard Specimen mm	Small-Size Specimens Proportional to Standard 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	2.000 ± 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
—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	3/8	10	1/4	6	3/16	5	5/32	4	3/32	2
A—Length of reduced section, min (Note 2)	2 1/4	60	1 3/4	45	1 1/4	32	3/4	20	5/8	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.

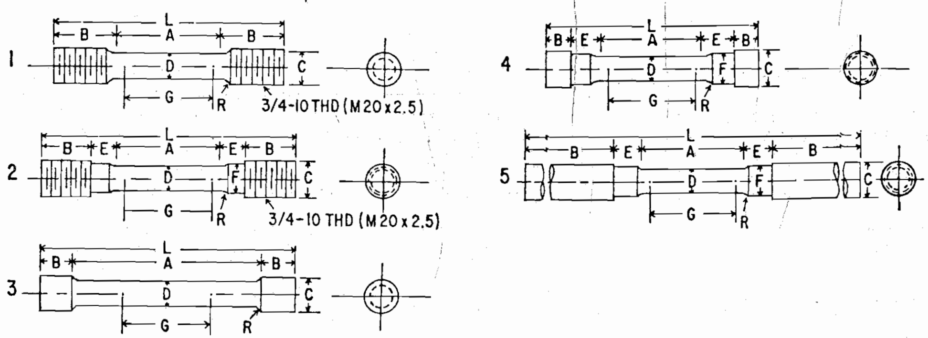
NOTE 3—The gage length and fillets shall be as shown, but the ends may be of any form to fit the holders of the testing machine in such a way that the load shall be axial (see Fig. 9). If the ends are to be held in wedge grips it is desirable, if possible, to make the length of the grip section great 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 Figs. 5 and 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 areas and multiplying factors.)

FIG. 5 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 Specimen.



DIMENSIONS

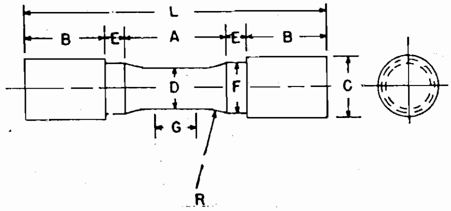
	Specimen 1		Specimen 2		Specimen 3		Specimen 4		Specimen 5	
	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm
G—Gage length	2.000 ± 0.005	50.0 ± 0.10	2.000 ± 0.005	50.0 ± 0.10	2.000 ± 0.005	50.0 ± 0.10	2.000 ± 0.005	50.0 ± 0.10	2.000 ± 0.005	50.0 ± 0.10
D—Diameter (Note 1)	0.500 ± 0.010	12.5 ± 0.25	0.500 ± 0.010	12.5 ± 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—Over-all length, approximate	5	125	5½	140	5½	140	4¾	120	9½	240
B—Length of end 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 use of UNF series of threads (¾ by 16, ½ by 20, ⅜ by 24, and ¼ by 28) is recommended for high-strength, brittle materials to avoid fracture in the thread portion.

FIG. 6 Various Types of Ends for Standard Round Tension Test Specimen.



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—Length of end 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—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. 7 Standard Tension Test Specimen for Cast Iron.

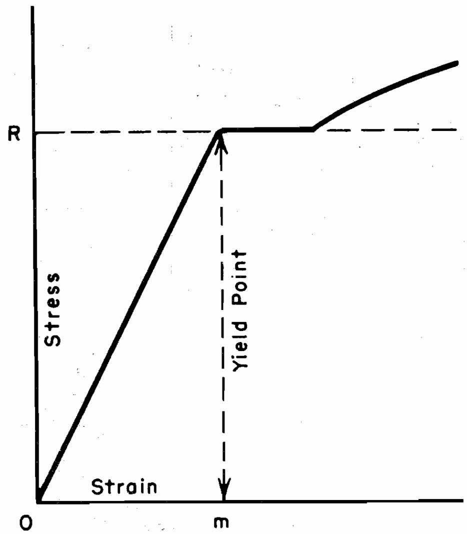


FIG. 8 Stress-Strain Diagram Showing Yield Point Corresponding with Top of Knee.

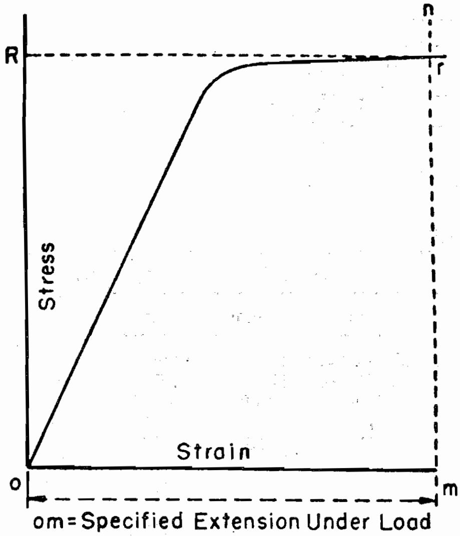


FIG. 9 Stress-Strain Diagram Showing Yield Point or Yield Strength by Extension Under Load Method.

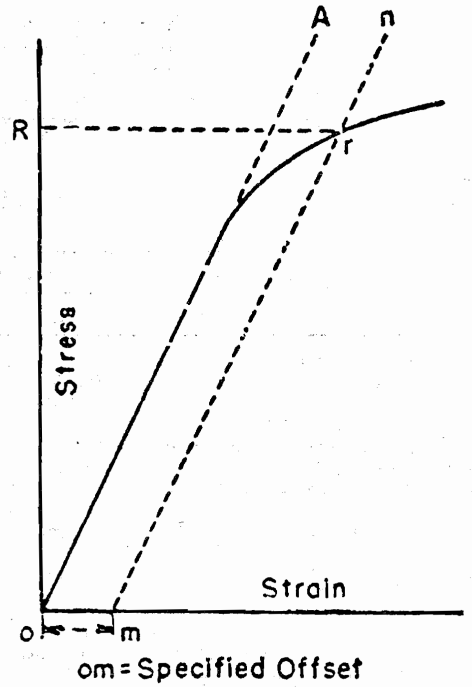
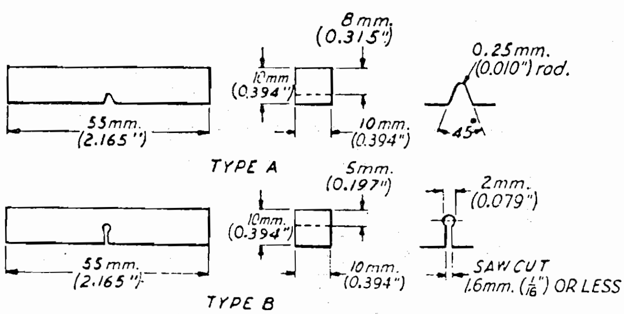


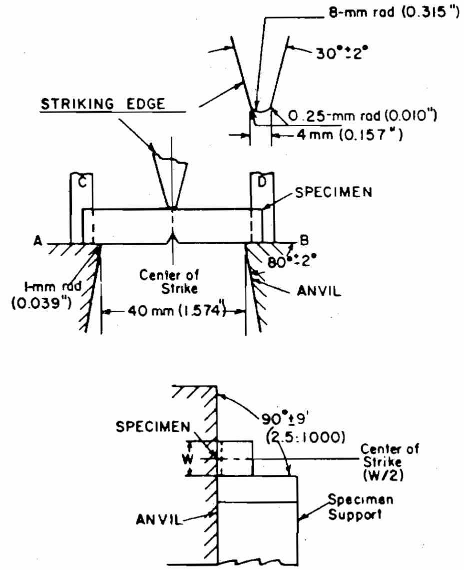
FIG. 10 Stress-Strain Diagram for Determination of Yield Strength by the Offset Method.



NOTE—Permissible variations shall be as follows:

Adjacent sides shall be at	90 deg ± 10 min
Cross section dimensions	±0.025 mm (0.001 in.)
Length of specimen	+0, −2.5 mm (0.100 in.)
Angle of notch	±1 deg
Radius of notch	±0.025 mm (0.001 in.)
Dimensions to bottom of notch:	
Specimen, Type A	8 ± 0.025 mm (0.315 ± 0.001 in.)
Specimen, Type B	5 ± 0.05 mm (0.197 ± 0.002 in.)
Finish	63 μin. (1.6 μm) max on notched surface and opposite face; 125 μin. (3.2 μm) max on other two surfaces

FIG. 11 Simple Beam Impact Test Specimens, Types A and B.



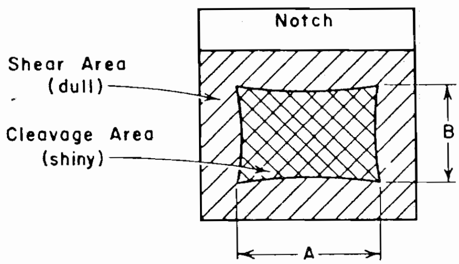
All dimensional tolerances shall be ± 0.05 mm (0.002 in.) unless otherwise specified.

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. 12 Charpy (Simple-Beam) Impact Test.



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 4 or Table 5.

FIG. 14 Determination of percent Shear Fracture.

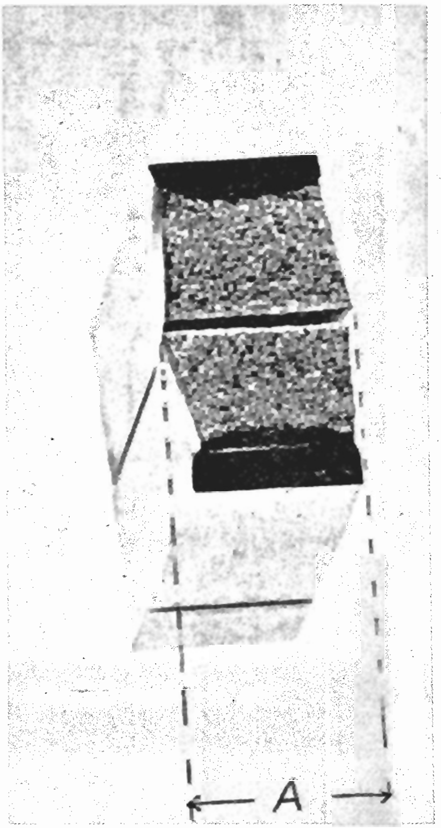


FIG. 13 Halves of Broken Charpy V-Notch Impact Specimen Joined for the Measurement of Lateral Expansion, Dimension *A*.

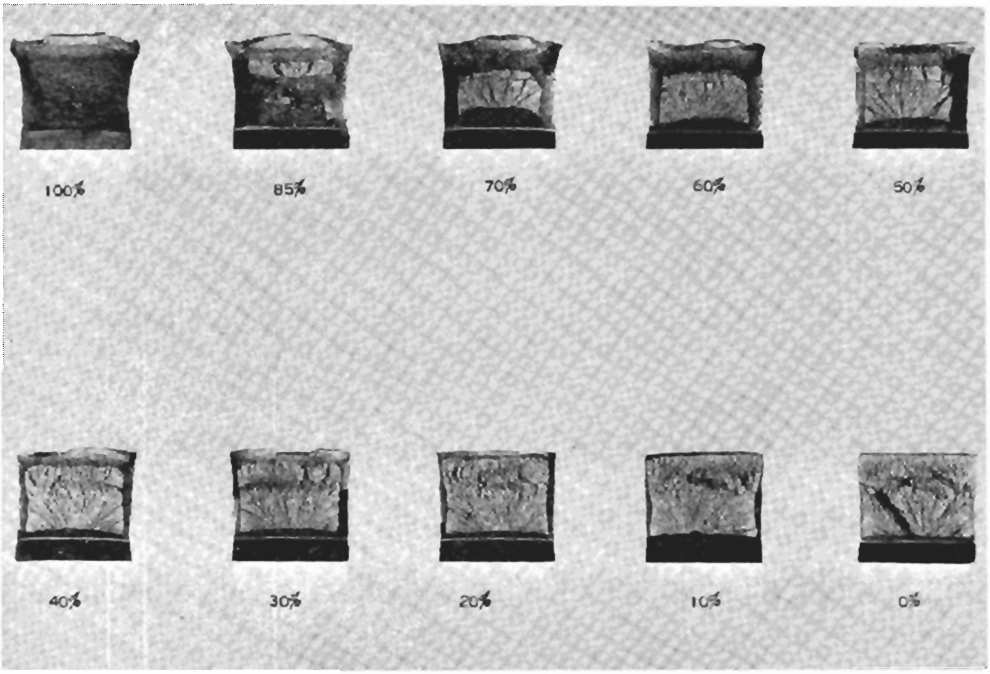


FIG. 15 Fracture Appearance Charts and percent Shear Fracture Comparator.

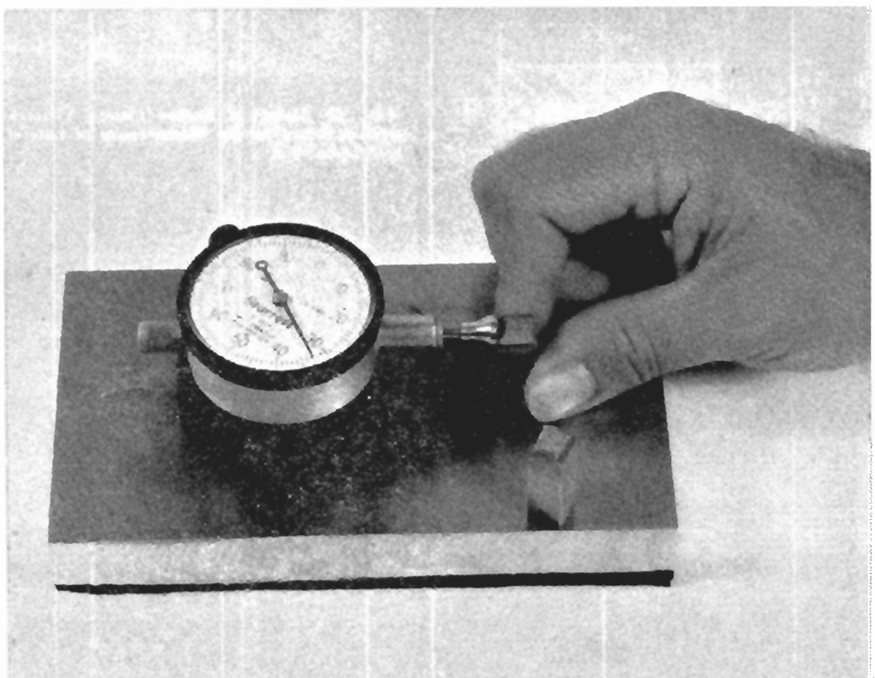
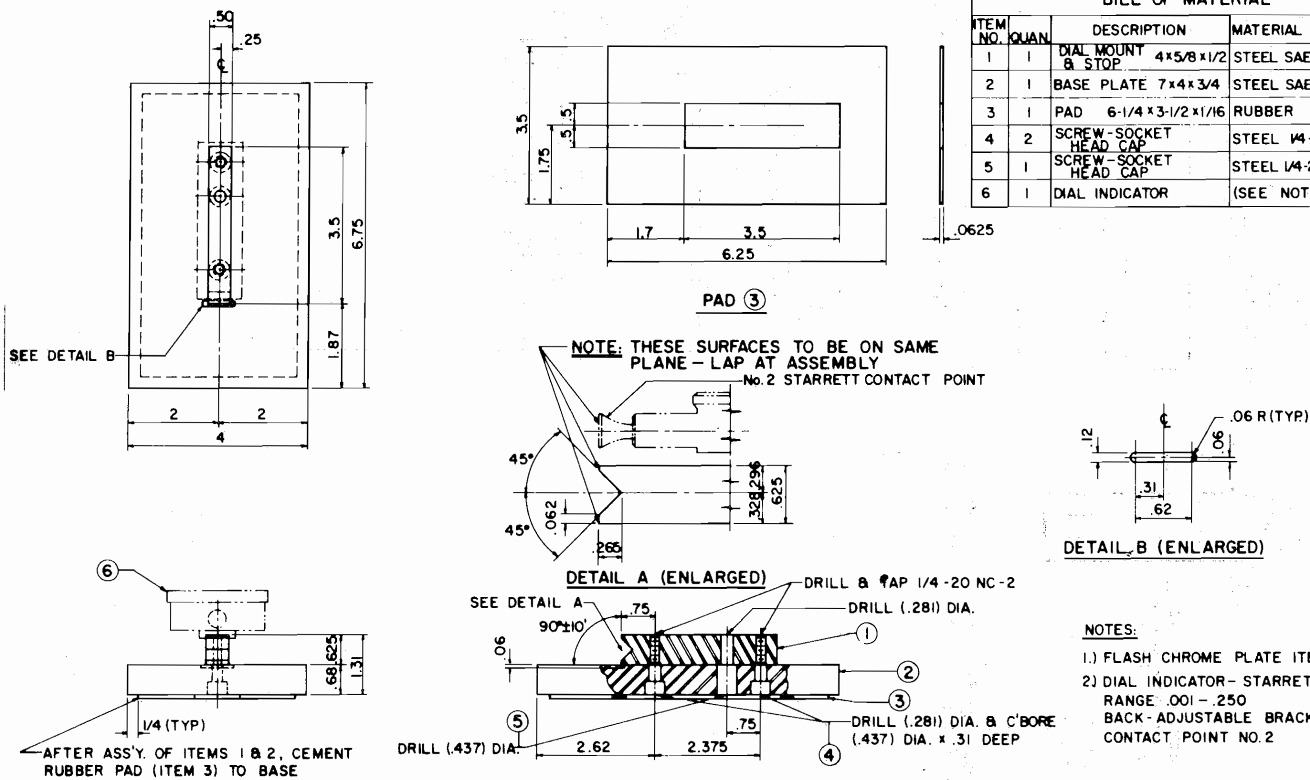


FIG. 16 Lateral Expansion Gage for Charpy Impact Specimens.



BILL OF MATERIAL

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

NOTES:

1.) FLASH CHROME PLATE ITEMS 1 & 2

2) DIAL INDICATOR – STARRETT NO. 25-241
RANGE .001 – .250
BACK-ADJUSTABLE BRACKET
CONTACT POINT NO. 2

FIG. 17 Assembly and Details for Lateral Expansion Gage.

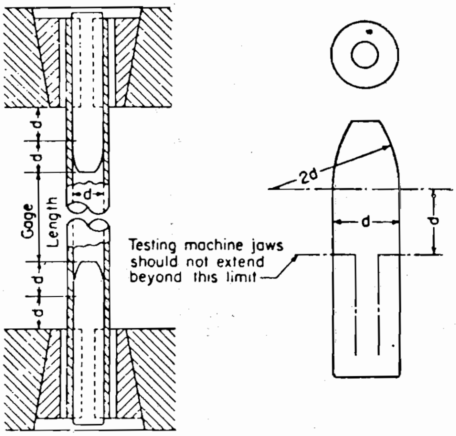


FIG. 18 Metal Plugs for Testing Tubular Specimens, Proper Location of Plugs in Specimen and of Specimen in Heads of Testing Machine.

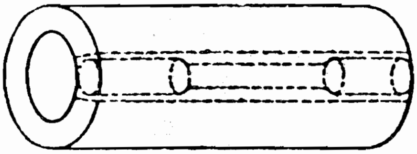
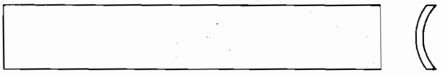
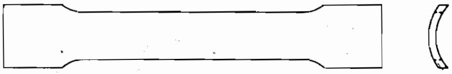


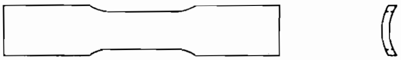
FIG. 19 Location of Longitudinal Tension Test Specimens in Large Diameter Tubing.



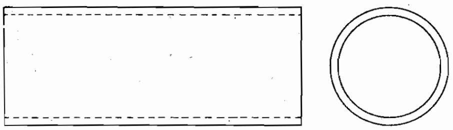
(*a*) Specimen for 8-in. Gage Length Test (Welded Only).



(*b*) Specimen for 8-in. Gage Length Test.

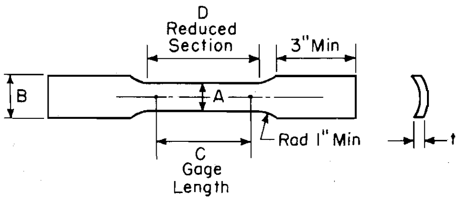


(*c*) Specimen for 2-in. Gage Length Test.



(*d*) Specimen for Full-Section Test.

FIG. 20 Longitudinal Tension Test Specimens for Large Diameter Tubing.



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

† Editorially corrected.

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.

FIG. 21 Dimensions and Tolerances for Longitudinal Tension Test Specimens for Large Diameter Tubing.

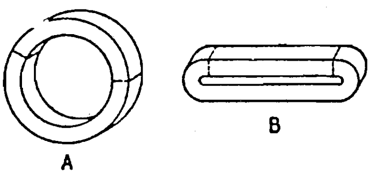


FIG. 22 Location of Transverse Tension Test Specimens in Ring Cut from Tubular Products.

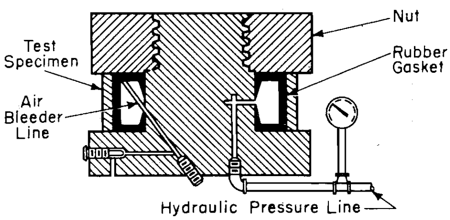
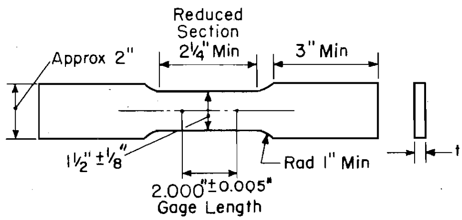


FIG. 24 Testing Machine for Determination of Transverse Yield Strength from Annular Ring Specimens.



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. 23 Transverse Tension Test Specimen Machined from Ring Cut from Tubular Products.

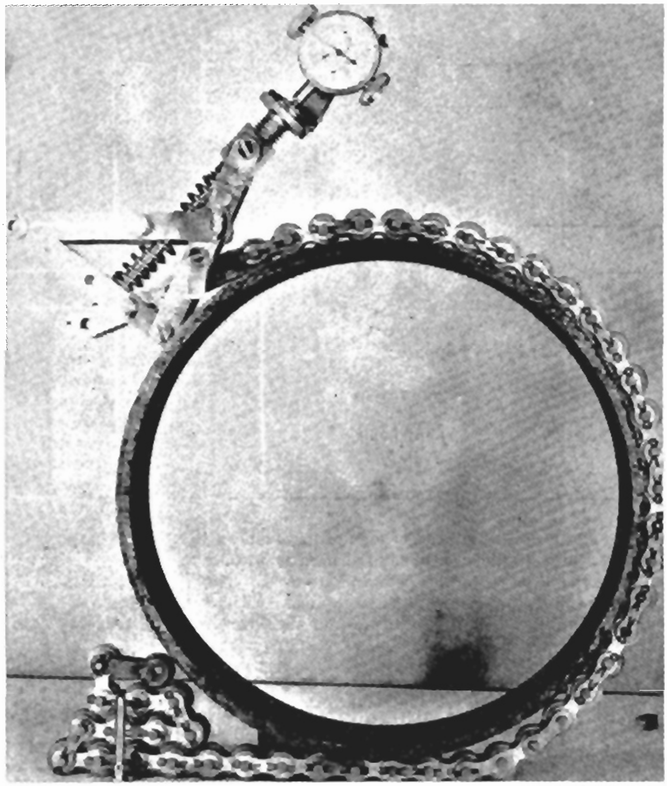


FIG. 25 Roller Chain Type Extensometer, Unclamped.

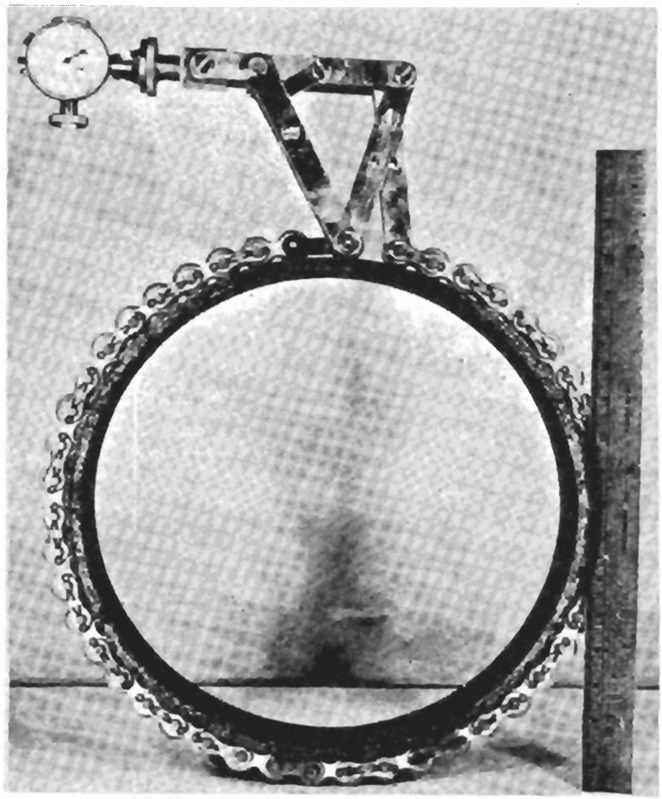


FIG. 26 Roller Chain Type Extensometer, Clamped.

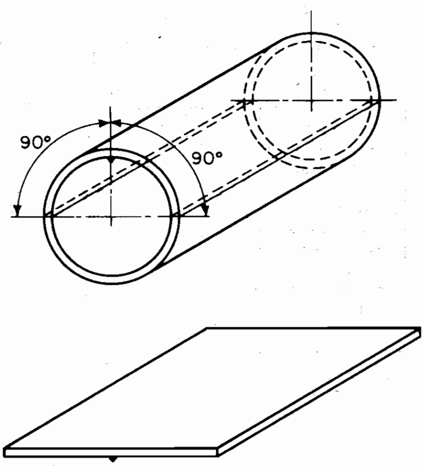


FIG. 27 Reverse Flattening Test.

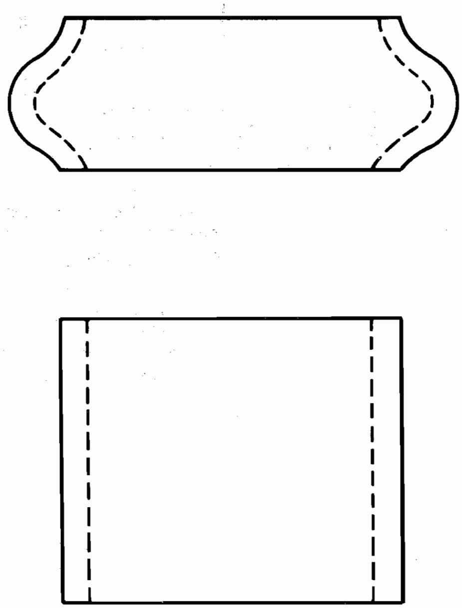
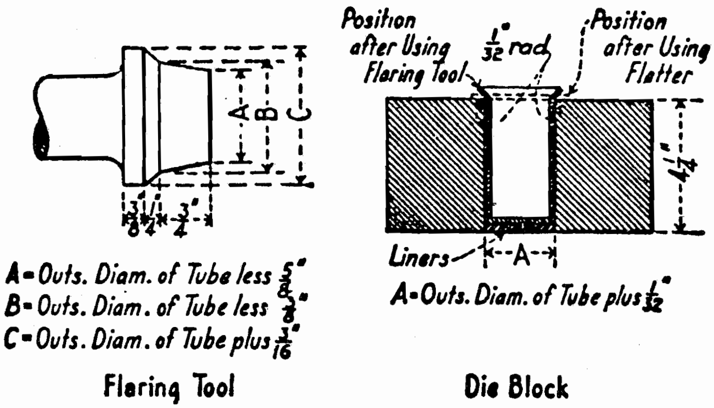


FIG. 28 Crush Test Specimen.



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

FIG. 29 Flaring Tool and Die Block for Flange Test.

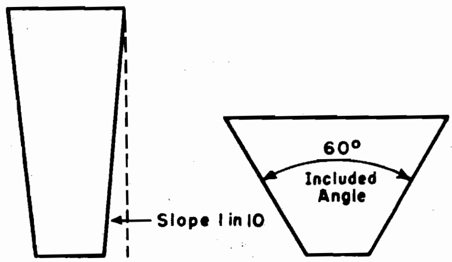
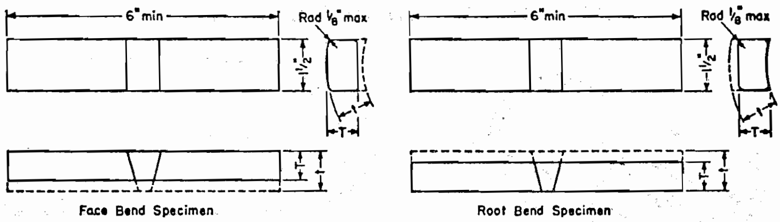


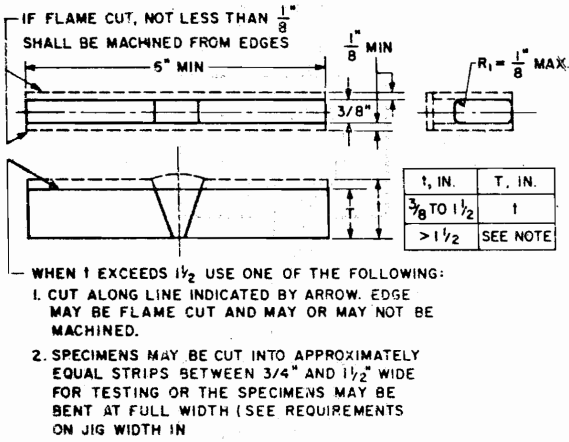
FIG. 30 Tapered Mandrels for Flaring Test.



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

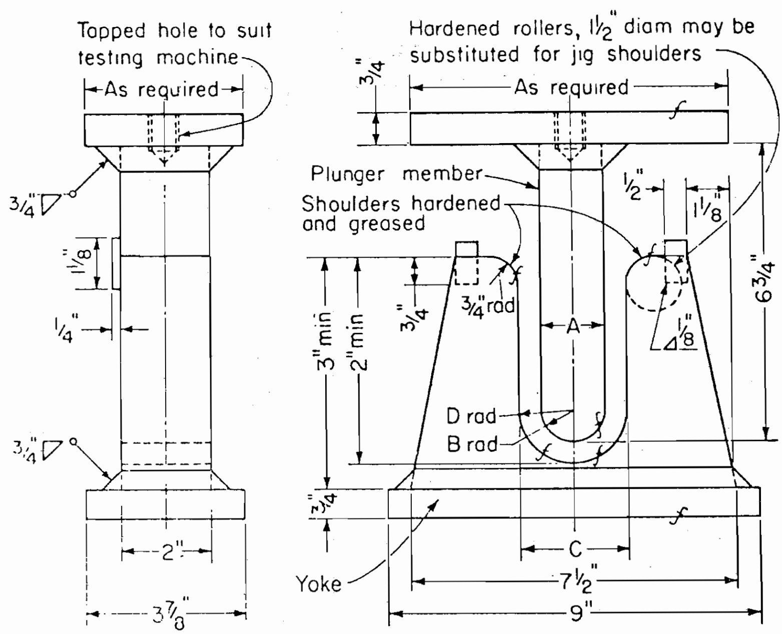
Pipe Wall Thickness (t), in.	Test Specimen Thickness, in.
Up to ⅜, incl	t
Over ⅜	⅜

FIG. 31(*a*) Transverse Face- and Root-Bend Test Specimens



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

FIG. 31(*b*) Side-Bend Specimen for Ferrous Materials



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

Test Specimen Thickness, in.	A	B	C	D
3/8	1 1/2	3/4	2 3/8	1 3/16
t	$4t$	$2t$	$6t + 1/8$	$3t + 1/16$

FIG. 32 Guided-Bend Test Jig.

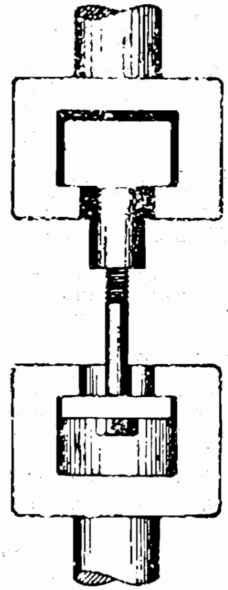
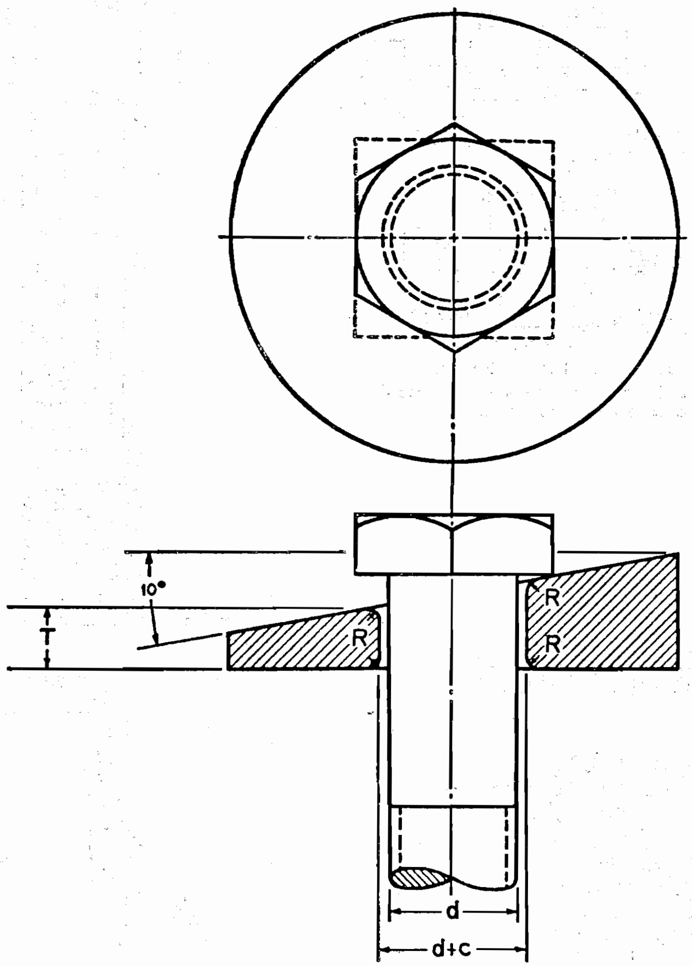
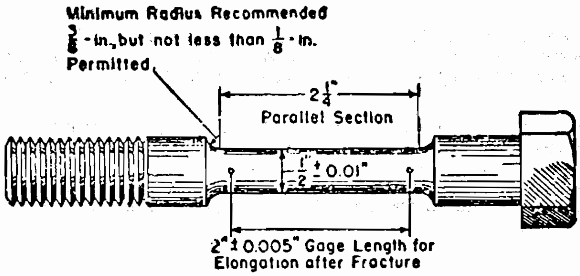


FIG. 33 Tension Testing Full-Size Bolt.



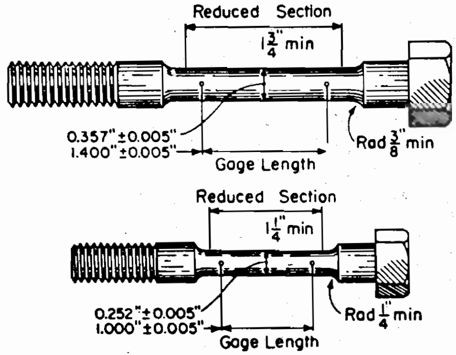
c = Clearance of wedge hole.
d = Diameter of bolt.
R = Radius.
T = Thickness of wedge at short side of hole equal to one-half diameter of bolt.

FIG. 34 Wedge Test Details.



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

FIG. 35 Tension Test Specimen for Bolt with Turned-Down Shank.



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

FIG. 36 Examples of Small Size Specimens Proportional to Standard 2-in. Gage Length Specimen.

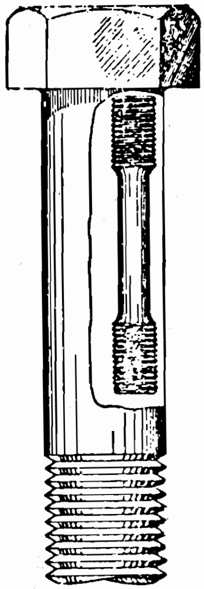


FIG. 37 Location of Standard Round 2-in. Gage Length Tension Test Specimen When Turned from Large Size Bolt.

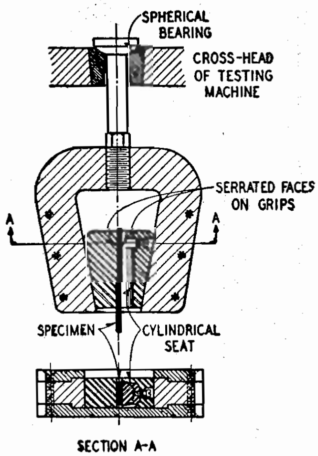


FIG. 38 Wedge-Type Gripping Device.

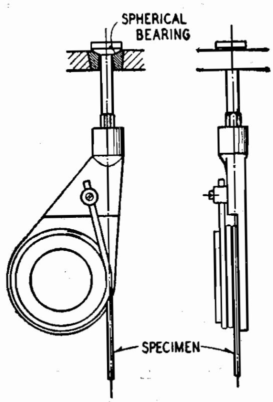


FIG. 39 Snubbing-Type Gripping Device.

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