EXHIBIT 150
PART 1

CERTIFICATE

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Legally Binding Document

By the Authority Vested By Part 5 of the United States Code § 552(a) and Part 1 of the Code of Regulations § 51 the attached document has been duly INCORPORATED BY REFERENCE and shall be considered legally binding upon all citizens and residents of the United States of America. *HEED THIS NOTICE*: Criminal penalties may apply for noncompliance.

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Standard Specification for Seamless Carbon Steel Pipe for High-Temperature Service[1]

This standard is issued under the fixed designation A 106/A 106M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This specification[2] covers seamless carbon steel pipe for high-temperature service (Note 1) in NPS ⅛ to NPS 48 [DN 6 to DN 1200] (Note 2) inclusive, with nominal (average) wall thickness as given in ASME B 36.10M. It shall be permissible to furnish pipe having other dimensions provided such pipe complies with all other requirements of this specification. Pipe ordered under this specification shall be suitable for bending, flanging, and similar forming operations, and for welding. When the steel is to be welded, it is presupposed that a welding procedure suitable to the grade of steel and intended use or service will be utilized.

NOTE 1—It is suggested, consideration be given to possible graphitization.

NOTE 2—The dimensionless designator NPS (nominal pipe size) [DN (diameter nominal)] has been substituted in this standard for such traditional terms as "nominal diameter," "size," and "nominal size."

1.2 Supplementary requirements of an optional nature are provided for seamless pipe intended for use in applications where a superior grade of pipe is required. These supplementary requirements call for additional tests to be made and when desired shall be so stated in the order.

1.3 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents. Therefore, each system is to be used independently of the other.

1.4 The following precautionary caveat pertains only to the test method portion, Sections 11, 12, 13, 14, and 15, of this specification: *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:* [3]

A 530/A 530M Specification for General Requirements for Specialized Carbon and Alloy Steel Pipe

E 213 Practice for Ultrasonic Examination of Metal Pipe and Tubing

E 309 Practice for Eddy-Current Examination of Steel Tubular Products Using Magnetic Saturation

E 381 Method of Macroetch Testing Steel Bars, Billets, Blooms, and Forgings

E 570 Practice for Flux Leakage Examination of Ferromagnetic Steel Tubular Products

2.2 *ASME Standard:*

ASME B 36.10M Welded and Seamless Wrought Steel Pipe[4]

2.3 *Military Standards:*

MIL-STD-129 Marking for Shipment and Storage[5]

MIL-STD-163 Steel Mill Products, Preparation for Shipment and Storage[5]

2.4 *Federal Standard:*

Fed. Std. No. 123 Marking for Shipments (Civil Agencies)[5]

Fed. Std. No. 183 Continuous Identification Marking of Iron and Steel Products[5]

2.5 *Other Standards:*

SSPC-SP 6 Surface Preparation Specification No. 6[6]

3. Ordering Information

3.1 The inclusion of the following, as required will describe the desired material adequately, when ordered under this specification:

3.1.1 Quantity (feet, metres, or number of lengths),

[1] This specification is under the jurisdiction of Committee A01 on Steel, Stainless Steel and Related Alloys and is the direct responsibility of Subcommittee A01.09 on Carbon Steel Tubular Products.

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[2] For ASME Boiler and Pressure Vessel Code applications see related Specifications SA-106 in Section II of that Code.

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

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

[5] Available from Standardization Documents Order Desk, DODSSP, Bldg. 4, Section D, 700 Robbins Ave., Philadelphia, PA 19111-5098.

[6] Available from Steel Structures Painting Council (SSPC), 40 24th St., 6th Floor, Pittsburgh, PA 15222-4656.

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

3.1.2 Name of material (seamless carbon steel pipe),

3.1.3 Grade (Table 1),

3.1.4 Manufacture (hot-finished or cold-drawn),

3.1.5 Size (NPS [DN] and weight class or schedule number, or both; outside diameter and nominal wall thickness; or inside diameter and nominal wall thickness),

3.1.6 Special outside diameter tolerance pipe (16.2.2),

3.1.7 Inside diameter tolerance pipe, over 10 in. [250 mm] ID (16.2.3),

3.1.8 Length (specific or random, Section 20),

3.1.9 Optional requirements (Section 9 and S1 to S8),

3.1.10 Test report required (Section on Certification of Specification A 530/A 530M),

3.1.11 Specification designation (A 106 or A 106M, including year-date),

3.1.12 End use of material,

3.1.13 Hydrostatic test in accordance with Specification A 530/A 530M or 13.3 of this specification, or NDE in accordance with Section 14 of this specification.

3.1.14 Special requirements.

4. Process

4.1 The steel shall be killed steel, with the primary melting process being open-hearth, basic-oxygen, or electric-furnace, possibly combined with separate degassing or refining. If secondary melting, using electroslag remelting or vacuum-arc remelting is subsequently employed, the heat shall be defined as all of the ingots remelted from a single primary heat.

4.2 Steel cast in ingots or strand cast is permissible. When steels of different grades are sequentially strand cast, identification of the resultant transition material is required. The producer shall remove the transition material by any established procedure that positively separates the grades.

4.3 For pipe NPS 1½ [DN 40] and under, it shall be permissible to furnish hot finished or cold drawn.

4.4 Unless otherwise specified, pipe NPS 2 [DN 50] and over shall be furnished hot finished. When agreed upon between the manufacturer and the purchaser, it is permissible to furnish cold-drawn pipe.

5. Heat Treatment

5.1 Hot-finished pipe need not be heat treated. Cold-drawn pipe shall be heat treated after the final cold draw pass at a temperature of 1200 °F (650 °C) or higher.

TABLE 1 Chemical Requirements

	Composition, %		
	Grade A	Grade B	Grade C
Carbon, max[A]	0.25	0.30	0.35
Manganese	0.27–0.93	0.29–1.06	0.29–1.06
Phosphorus, max	0.035	0.035	0.035
Sulfur, max	0.035	0.035	0.035
Silicon, min	0.10	0.10	0.10
Chrome, max[B]	0.40	0.40	0.40
Copper, max[B]	0.40	0.40	0.40
Molybdenum, max[B]	0.15	0.15	0.15
Nickel, max[B]	0.40	0.40	0.40
Vanadium, max[B]	0.08	0.08	0.08

[A] For each reduction of 0.01 % below the specified carbon maximum, an increase of 0.06 % manganese above the specified maximum will be permitted up to a maximum of 1.35 %.

[B] These five elements combined shall not exceed 1 %.

6. General Requirements

6.1 Material furnished to this specification shall conform to the applicable requirements of the current edition of Specification A 530/A 530M unless otherwise provided herein.

7. Chemical Composition

7.1 The steel shall conform to the requirements as to chemical composition prescribed in Table 1.

8. Heat Analysis

8.1 An analysis of each heat of steel shall be made by the steel manufacturer to determine the percentages of the elements specified in Section 7. If the secondary melting processes of 5.1 are employed, the heat analysis shall be obtained from one remelted ingot or the product of one remelted ingot of each primary melt. The chemical composition thus determined, or that determined from a product analysis made by the manufacturer, if the latter has not manufactured the steel, shall be reported to the purchaser or the purchaser's representative, and shall conform to the requirements specified in Section 7.

9. Product Analysis

9.1 At the request of the purchaser, analyses of two pipes from each lot (Note 3) of 400 lengths or fraction thereof, of each size up to, but not including, NPS 6 [DN 150], and from each lot of 200 lengths or fraction thereof of each size NPS 6 [DN 150] and over, shall be made by the manufacturer from the finished pipe. The results of these analyses shall be reported to the purchaser or the purchaser's representative and shall conform to the requirements specified in Section 7.

9.2 If the analysis of one of the tests specified in 9.1 does not conform to the requirements specified in Section 7, analyses shall be made on additional pipes of double the original number from the same lot, each of which shall conform to requirements specified.

NOTE 3—A lot shall consist of the number of lengths specified in Sections 9 and 21 of the same size and wall thickness from any one heat of steel.

10. Tensile Requirements

10.1 The material shall conform to the requirements as to tensile properties given in Table 2.

11. Bending Requirements

11.1 For pipe NPS 2 [DN 50] and under, a sufficient length of pipe shall stand being bent cold through 90° around a cylindrical mandrel, the diameter of which is twelve times the outside diameter (as shown in ASME B 36.10M) of the pipe, without developing cracks. When ordered for close coiling, the pipe shall stand being bent cold through 180° around a cylindrical mandrel, the diameter of which is eight times the outside diameter (as shown in ASME B 36.10M) of the pipe, without failure.

11.2 Subject to the approval of the purchaser, for pipe whose diameter exceeds 10 in. [250 mm], it shall be permissible for the bend test to be substituted for the flattening test described in Section 12. The bend test specimens shall be bent at room temperature through 180° with the inside diameter of

TABLE 2 Tensile Requirements

	Grade A		Grade B		Grade C	
Tensile strength, min, psi [MPa]	48 000 [330]		60 000 [415]		70 000 [485]	
Yield strength, min, psi [MPa]	30 000 [205]		35 000 [240]		40 000 [275]	
	Longitudinal	Transverse	Longitudinal	Transverse	Longitudinal	Transverse
Elongation in 2 in. [50 mm], min, %:						
Basic minimum elongation transverse strip tests, and for all small sizes tested in full section	35	25	30	16.5	30	16.5
When standard round 2-in. [50-mm] gage length test specimen is used	28	20	22	12	20	12
For longitudinal strip tests	A		A		A	
For transverse strip tests, a deduction for each 1/32-in. [0.8-mm] decrease in wall thickness below 5/16 in. [7.9 mm] from the basic minimum elongation of the following percentage shall be made		1.25		1.00		1.00

A The minimum elongation in 2 in. [50 mm] shall be determined by the following equation:

$$e = 625\ 000A^{0.2} / U^{0.9}$$

for SI units, and

$$e = 1\ 940A^{0.2} / U^{0.9}$$

for inch-pound units,

where:

e = minimum elongation in 2 in. [50 mm], %, rounded to the nearest 0.5 %,

A = cross-sectional area of the tension test specimen, in.^{2} [mm^2], based upon specified outside diameter or nominal specimen width and specified wall thickness, rounded to the nearest 0.01 in.^{2} [1 mm^2]. (If the area thus calculated is equal to or greater than 0.75 in.^{2} [500 mm^2], then the value 0.75 in.^{2} [500 mm^2] shall be used.), and

U = specified tensile strength, psi [MPa].

the bend being 1 in. [25 mm], without cracking on the outside portion of the bent portion.

11.3 For pipe whose diameter exceeds 25 in. [635 mm] and whose diameter to wall thickness ratio is 7.0 or less, the bend test described in 11.2 shall be conducted instead of the flattening test.

NOTE 4—Diameter to wall thickness ratio = specified outside diameter/nominal wall thickness.

Example: For 28 in. [711 mm] diameter 5.000 in. [127 mm] thick pipe the diameter to wall thickness ratio = 28/5 = 5.6 [711/127 = 5.6].

12. Flattening Tests

12.1 Except as allowed by 11.2, for pipe over NPS 2 [DN 50], a section of pipe not less than 2½ in. [63.5 mm] in length shall be flattened cold between parallel plates until the opposite walls of the pipe meet. Flattening tests shall be in accordance with Specification A 530/A 530M, except that in the formula used to calculate the "*H*" value, the following "*e*" constants shall be used:

0.08 for Grade A
0.07 for Grades B and C

12.2 When low *D*-to-*t* ratio tubulars are tested, because the strain imposed due to geometry is unreasonably high on the inside surface at the six and twelve o'clock locations, cracks at these locations shall not be cause for rejection if the *D*-to-*t* ratio is less than ten.

13. Hydrostatic Test

13.1 Except as allowed by 13.2, 13.3, and 13.4, each length of pipe shall be subjected to the hydrostatic test without leakage through the pipe wall.

13.2 As an alternative to the hydrostatic test at the option of the manufacturer or where specified in the purchase order, it shall be permissible for the full body of each pipe to be tested with a nondestructive electric test described in Section 14.

13.3 Where specified in the purchase order, it shall be permissible for pipe to be furnished without the hydrostatic test and without the nondestructive electric test in Section 14; in this case, each length so furnished shall include the mandatory marking of the letters "NH." It shall be permissible for pipe meeting the requirements of 13.1 or 13.2 to be furnished where pipe without either the hydrostatic or nondestructive electric test has been specified in the purchase order; in this case, such pipe need not be marked with the letters "NH." Pipe that has failed either the hydrostatic test of 13.1 or the nondestructive electric test of 13.2 shall not be furnished as "NH" pipe.

13.4 Where the hydrostatic test and the nondestructive electric test are omitted and the lengths marked with the letters "NH," the certification, where required, shall clearly state "Not Hydrostatically Tested," and the letters "NH" shall be appended to the product specification number and material grade shown on the certification.

14. Nondestructive Electric Test

14.1 As an alternative to the hydrostatic test at the option of the manufacturer or where specified in the purchase order as an alternative or addition to the hydrostatic test, the full body of each pipe shall be tested with a nondestructive electric test in accordance with Practice E 213, E 309, or E 570. In such cases, the marking of each length of pipe so furnished shall include the letters "NDE." It is the intent of this nondestructive electric test to reject pipe with imperfections that produce test signals equal to or greater than that produced by the applicable calibration standard.

14.2 Where the nondestructive electric test is performed, the lengths shall be marked with the letters "NDE." The certification, where required, shall state "Nondestructive Electric Tested" and shall indicate which of the tests was applied. Also, the letters "NDE" shall be appended to the product specification number and material grade shown on the certification.

14.3 The following information is for the benefit of the user of this specification:

14.3.1 The reference standards defined in 14.4 through 14.6 are convenient standards for calibration of nondestructive testing equipment. The dimensions of such standards are not to be construed as the minimum sizes of imperfections detectable by such equipment.

14.3.2 The ultrasonic testing referred to in this specification is capable of detecting the presence and location of significant longitudinally or circumferentially oriented imperfections: however, different techniques need to be employed for the detection of such differently oriented imperfections. Ultrasonic testing is not necessarily capable of detecting short, deep imperfections.

14.3.3 The eddy current examination referenced in this specification has the capability of detecting significant imperfections, especially of the short abrupt type.

14.3.4 The flux leakage examination referred to in this specification is capable of detecting the presence and location of significant longitudinally or transversely oriented imperfections: however, different techniques need to be employed for the detection of such differently oriented imperfections.

14.3.5 The hydrostatic test referred to in Section 13 has the capability of finding defects of a size permitting the test fluid to leak through the tube wall and may be either visually seen or detected by a loss of pressure. Hydrostatic testing is not necessarily capable of detecting very tight, through-the-wall imperfections or imperfections that extend an appreciable distance into the wall without complete penetration.

14.3.6 A purchaser interested in ascertaining the nature (type, size, location, and orientation) of discontinuities that can be detected in the specific applications of these examinations is directed to discuss this with the manufacturer of the tubular product.

14.4 For ultrasonic testing, the calibration reference notches shall be, at the option of the producer, any one of the three common notch shapes shown in Practice E 213. The depth of notch shall not exceed 12½ % of the specified wall thickness of the pipe or 0.004 in. [0.1 mm], whichever is greater.

14.5 For eddy current testing, the calibration pipe shall contain, at the option of the producer, any one of the following discontinuities to establish a minimum sensitivity level for rejection:

14.5.1 *Drilled Hole*—The calibration pipe shall contain depending upon the pipe diameter three holes spaced 120° apart or four holes spaced 90° apart and sufficiently separated longitudinally to ensure separately distinguishable responses. The holes shall be drilled radially and completely through the pipe wall, care being taken to avoid distortion of the pipe while drilling. Depending upon the pipe diameter the calibration pipe shall contain the following hole:

NPS	DN	Diameter of Drilled Hole
≤ ½	≤ 15	0.039 in. [1 mm]
> ½ ≤ 1¼	> 15 ≤ 32	0.055 in. [1.4 mm]
> 1¼ ≤ 2	> 32 ≤ 50	0.071 in. [1.8 mm]
> 2 ≤ 5	> 50 ≤ 125	0.087 in. [2.2 mm]
>5	> 125	0.106 in. [2.7 mm]

14.5.2 *Transverse Tangential Notch*—Using a round tool or file with a ¼-in. [6-mm] diameter, a notch shall be filed or milled tangential to the surface and transverse to the longitudinal axis of the pipe. The notch shall have a depth not exceeding 12 ½ % of the specified wall thickness of the pipe or 0.004 in. [0.1 mm], whichever is greater.

14.5.3 *Longitudinal Notch*—A notch 0.031 in. [0.8 mm] or less in width shall be machined in a radial plane parallel to the tube axis on the outside surface of the pipe, to have a depth not exceeding 12 ½ % of the specified wall thickness of the tube or 0.004 in. [0.1 mm], whichever is greater. The length of the notch shall be compatible with the testing method.

14.5.4 *Compatibility*—The discontinuity in the calibration pipe shall be compatible with the testing equipment and the method being used.

14.6 For flux leakage testing, the longitudinal calibration reference notches shall be straight-sided notches machined in a radial plane parallel to the pipe axis. For wall thicknesses under ½ in. [12.7 mm], outside and inside notches shall be used; for wall thicknesses equal to and above ½ in. [12.7 mm], only an outside notch shall be used. Notch depth shall not exceed 12½ % of the specified wall thickness, or 0.004 in. [0.1 mm], whichever is greater. Notch length shall not exceed 1 in. [25 mm], and the width shall not exceed the depth. Outside diameter and inside diameter notches shall be located sufficiently apart to allow separation and identification of the signals.

14.7 Pipe containing one or more imperfections that produce a signal equal to or greater than the signal produced by the calibration standard shall be rejected or the area producing the signal shall be reexamined.

14.7.1 Test signals produced by imperfections which cannot be identified, or produced by cracks or crack-like imperfections shall result in rejection of the pipe, unless it is repaired and retested. To be accepted, the pipe must pass the same specification test to which it was originally subjected, provided that the remaining wall thickness is not decreased below that permitted by this specification. The OD at the point of grinding may be reduced by the amount so reduced.

14.7.2 Test signals produced by visual imperfections such as those listed below may be evaluated in accordance with the provisions of Section 18:

14.7.2.1 Dinges,

14.7.2.2 Straightener marks,

14.7.2.3 Cutting chips,

14.7.2.4 Scratches,

14.7.2.5 Steel die stamps,

14.7.2.6 Stop marks, or

14.7.2.7 Pipe reducer ripple.

14.8 The test methods described in this section are not necessarily capable of inspecting the end portion of pipes, a condition referred to as "end effect." The length of such end effect shall be determined by the manufacturer and, when specified in the purchase order, reported to the purchaser.

15. Nipples

15.1 Nipples shall be cut from pipe of the same dimensions and quality described in this specification.

16. Dimensions, Mass, and Permissible Variations

16.1 *Mass*—The mass of any length of pipe shall not vary more than 10 % over and 3.5 % under that specified. Unless otherwise agreed upon between the manufacturer and the purchaser, pipe in NPS 4 [DN 100] and smaller may be weighed in convenient lots; pipe larger than NPS 4 [DN 100] shall be weighed separately.

16.2 *Diameter*—The tolerances for diameter shall be in accordance with the following:

16.2.1 Except for pipe ordered as special outside diameter tolerance pipe or as inside diameter tolerance pipe, variations in outside diameter shall not exceed those given in Table 3.

16.2.2 For pipe over 10 in. [250 mm] OD ordered as special outside diameter tolerance pipe, the outside diameter shall not vary more than 1 % over or 1 % under the specified outside diameter.

16.2.3 For pipe over 10 in. [250 mm] ID ordered as inside diameter tolerance pipe, the inside diameter shall not vary more than 1 % over or 1 % under the specified inside diameter.

16.3 *Thickness*—The minimum wall thickness at any point shall not be more than 12.5 % under the specified wall thickness.

17. Lengths

17.1 Pipe lengths shall be in accordance with the following regular practice:

17.1.1 The lengths required shall be specified in the order, and

17.1.2 No jointers are permitted unless otherwise specified.

17.1.3 If definite lengths are not required, pipe may be ordered in single random lengths of 16 to 22 ft [4.8 to 6.7 m] with 5 % 12 to 16 ft [3.7 to 4.8 m], or in double random lengths with a minimum average of 35 ft [10.7 m] and a minimum length of 22 ft [6.7 m] with 5 % 16 to 22 ft [4.8 to 6.7 m].

TABLE 3 Variations in Outside Diameter

NPS [DN Designator]	Permissible Variations in Outside Diameter			
	Over		Under	
	in.	mm	in.	mm
1⁄8 to 11⁄2 [6 to 40], incl	1⁄64 (0.015)	0.4	1⁄64 (0.015)	0.4
Over 11⁄2 to 4 [40 to 100], incl	1⁄32 (0.031)	0.8	1⁄32 (0.031)	0.8
Over 4 to 8 [100 to 200], incl	1⁄16 (0.062)	1.6	1⁄32 (0.031)	0.8
Over 8 to 18 [200 to 450], incl	3⁄32 (0.093)	2.4	1⁄32 (0.031)	0.8
Over 18 to 26 [450 to 650], incl	1⁄8 (0.125)	3.2	1⁄32 (0.031)	0.8
Over 26 to 34 [650 to 850], incl	5⁄32 (0.156)	4.0	1⁄32 (0.031)	0.8
Over 34 to 48 [850 to 1200], incl	3⁄16 (0.187)	4.8	1⁄32 (0.031)	0.8

18. Workmanship, Finish and Appearance

18.1 The pipe manufacturer shall explore a sufficient number of visual surface imperfections to provide reasonable assurance that they have been properly evaluated with respect to depth. Exploration of all surface imperfections is not required but consideration should be given to the necessity of exploring all surface imperfections to assure compliance with 18.2.

18.2 Surface imperfections that penetrate more than 121⁄2 % of the nominal wall thickness or encroach on the minimum wall thickness shall be considered defects. Pipe with such defects shall be given one of the following dispositions:

18.2.1 The defect shall be removed by grinding, provided that the remaining wall thickness is within the limits specified in 16.3.

18.2.2 Repaired in accordance with the repair welding provisions of 18.6.

18.2.3 The section of pipe containing the defect may be cut off within the limits of requirements on length.

18.2.4 Rejected.

18.3 To provide a workmanlike finish and basis for evaluating conformance with 18.2 the pipe manufacturer shall remove by grinding the following noninjurious imperfections:

18.3.1 Mechanical marks, abrasions (Note 5) and pits, any of which imperfections are deeper than 1⁄16 in. [1.6 mm].

18.3.2 Visual imperfections commonly referred to as scabs, seams, laps, tears, or slivers found by exploration in accordance with 18.1 to be deeper than 5 % of the nominal wall thickness.

18.4 At the purchaser's discretion, pipe shall be subjected to rejection if surface imperfections acceptable under 18.2 are not scattered, but appear over a large area in excess of what is considered a workmanlike finish. Disposition of such pipe shall be a matter of agreement between the manufacturer and the purchaser.

18.5 When imperfections or defects are removed by grinding, a smooth curved surface shall be maintained, and the wall thickness shall not be decreased below that permitted by this specification. The outside diameter at the point of grinding is permitted to be reduced by the amount so removed.

18.5.1 Wall thickness measurements shall be made with a mechanical caliper or with a properly calibrated nondestructive testing device of appropriate accuracy. In case of dispute, the measurement determined by use of the mechanical caliper shall govern.

18.6 Weld repair shall be permitted only subject to the approval of the purchaser and in accordance with Specification A 530/A 530M.

18.7 The finished pipe shall be reasonably straight.

NOTE 5—Marks and abrasions are defined as cable marks, dinges, guide marks, roll marks, ball scratches, scores, die marks, etc.

19. End Finish

19.1 The Pipe shall be furnished to the following practice, unless otherwise specified.

19.1.1 *NPS 1½ [DN 40] and Smaller*—All walls shall be either plain-end square cut, or plain-end beveled at the option of the manufacturer.

19.1.2 *NPS 2 [DN 50] and Larger*—Walls through extra strong weights, shall be plain-end-beveled.

19.1.3 *NPS 2 [DN 50] and Larger*—Walls over extra strong weights, shall be plain-end square cut.

NOTE 6—Plain-end beveled is defined as plain-end pipe having a bevel angle of 30°, +5° or -0°, as measured from a line drawn perpendicular to the axis of the pipe with a root face of 1⁄16 ± 1⁄32 in. [1.6 ± 0.8 mm]. Other bevel angles may be specified by agreement between the purchaser and the manufacturer.

20. Number of Tests

20.1 The tensile requirements specified in Section 7 shall be determined on one length of pipe from each lot (Note 3) of 400 lengths or fraction thereof of each size under NPS 6 [DN 150], and from each lot of 200 lengths or fraction thereof of each size NPS 6 [DN 150] and over.

20.2 For pipe NPS 2 [DN 50] and under, the bend test specified in 11.1 shall be made on one pipe from each lot of 400 lengths or fraction thereof of each size. The bend test, where used as permitted by 11.2 or required by 11.3, shall be made on one end of 5 % of the pipe from each lot. For small lots, at least one pipe shall be tested.

20.3 The flattening test specified in Section 12 shall be made on one length of pipe from each lot of 400 lengths or fraction thereof of each size over NPS 2 [DN 50], up to but not including NPS 6 [DN 150], and from each lot of 200 lengths or fraction thereof, of each size NPS 6 [DN 150] and over.

20.4 If any test specimen shows flaws or defective machining, it shall be permissible to discard it and substitute another test specimen.

21. Retests

21.1 If the percentage of elongation of any tension test specimen is less than that given in Table 1 and any part of the fracture is more than ¾ in. [19 mm] from the center of the gage length of a 2-in. [50-mm] specimen as indicated by scribe scratches marked on the specimen before testing, a retest shall be allowed. If a specimen breaks in an inside or outside surface flaw, a retest shall be allowed.

21.2 Should a crop end of a finished pipe fail in the flattening test, one retest is permitted to be made from the failed end. Pipe shall be normalized either before or after the first test, but pipe shall be subjected to only two normalizing treatments.

22. Test Specimens and Test Methods

22.1 On NPS 8 [DN 200] and larger, specimens cut either longitudinally or transversely shall be acceptable for the tension test. On sizes smaller than NPS 8 [DN 200], the longitudinal test only shall be used.

22.2 When round tension test specimens are used for pipe wall thicknesses over 1.0 in. [25.4 mm], the mid-length of the longitudinal axis of such test specimens shall be from a location midway between the inside and outside surfaces of the pipe.

22.3 Test specimens for the bend test specified in Section 11 and for the flattening tests shall consist of sections cut from a pipe. Specimens for flattening tests shall be smooth on the ends and free from burrs, except when made on crop ends.

22.4 Test specimens for the bend test specified in 11.2 and 11.3 shall be cut from one end of the pipe and, unless otherwise specified, shall be taken in a transverse direction. One test specimen shall be taken as close to the outer surface as possible and another from as close to the inner surface as possible. The specimens shall be either ½ by ½ in. [12.5 by 12.5 mm] in section or 1 by ½ in. [25 by 12.5 mm] in section with the corners rounded to a radius not over 1⁄16 in. [1.6 mm] and need not exceed 6 in. [150 mm] in length. The side of the samples placed in tension during the bend shall be the side closest to the inner and outer surface of the pipe respectively.

22.5 All routine check tests shall be made at room temperature.

23. Certification

23.1 When test reports are requested, in addition to the requirements of Specification A 530/A 530M, the producer or supplier shall furnish to the purchaser a chemical analysis report for the elements specified in Table 1.

24. Product Marking

24.1 In addition to the marking prescribed in Specification A 530/A 530M, the marking shall include heat number, the information as per Table 4, an additional symbol "S" if one or more of the supplementary requirements apply; the length, OD 1 %, if ordered as special outside diameter tolerance pipe; ID 1 %, if ordered as special inside diameter tolerance pipe; the schedule number, weight class, or nominal wall thickness; and, for sizes larger than NPS 4 [DN 100], the weight. Length shall be marked in feet and tenths of a foot [metres to two decimal places], depending on the units to which the material was ordered, or other marking subject to agreement. For sizes NPS 1½ , 1¼ , 1, and ¾ [DN 40, 32, 25, and 20], each length shall be marked as prescribed in Specification A 530/A 530M. These sizes shall be bundled in accordance with standard mill practice and the total bundle footage marked on the bundle tag; individual lengths of pipe need not be marked with footage. For sizes less than NPS ¾ [DN 20], all the required markings shall be on the bundle tag or on each length of pipe and shall include the total footage; individual lengths of pipe need not be marked with footage. If not marked on the bundle tag, all required marking shall be on each length.

24.2 When pipe sections are cut into shorter lengths by a subsequent processor for resale as material, the processor shall

TABLE 4 Marking

Hydro	NDE	Marking
Yes	No	Test Pressure
No	Yes	NDE
No	No	NH
Yes	Yes	Test Pressure/NDE

transfer complete identifying information, including the name or brand of the manufacturer to each unmarked cut length, or to metal tags securely attached to bundles of unmarked small diameter pipe. The same material designation shall be included with the information transferred, and the processor's name, trademark, or brand shall be added.

24.3 *Bar Coding*—In addition to the requirements in 24.1 and 24.2, bar coding is acceptable as a supplementary identification method. The purchaser may specify in the order a specific bar coding system to be used.

25. Government Procurement

25.1 When specified in the contract, material shall be preserved, packaged, and packed in accordance with the requirements of MIL-STD-163. The applicable levels shall be as specified in the contract. Marking for the shipment of such material shall be in accordance with Fed. Std. No. 123 for civil agencies and MIL-STD-129 or Fed. Std. No. 183 if continuous marking is required for military agencies.

25.2 *Inspection*—Unless otherwise specified in the contract, the producer is responsible for the performance of all inspection and test requirements specified herein. Except as otherwise specified in the contract, the producer shall use his own, or any other suitable facilities for the performance of the inspection and test requirements specified herein, unless disapproved by the purchaser. The purchaser shall have the right to perform any of the inspections and tests set forth in this specification where such inspections are deemed necessary to ensure that the material conforms to the prescribed requirements.

26. Keywords

26.1 carbon steel pipe; seamless steel pipe; steel pipe

SUPPLEMENTARY REQUIREMENTS

One or more of the following supplementary requirements shall apply only when specified in the purchase order. The purchaser may specify a different frequency of test or analysis than is provided in the supplementary requirement. Subject to agreement between the purchaser and manufacturer, retest and retreatment provisions of these supplementary requirements may also be modified.

S1. Product Analysis

S1.1 Product analysis shall be made on each length of pipe. Individual lengths failing to conform to the chemical composition requirements shall be rejected.

S2. Transverse Tension Test

S2.1 A transverse tension test shall be made on a specimen from one end or both ends of each pipe NPS 8 [DN 200] and over. If this supplementary requirement is specified, the number of tests per pipe shall also be specified. If a specimen from any length fails to meet the required tensile properties (tensile, yield, and elongation), that length shall be rejected subject to retreatment in accordance with Specification A 530/A 530M and satisfactory retest.

S3. Flattening Test

S3.1 The flattening test of Specification A 530/A 530M shall be made on a specimen from one end or both ends of each pipe. Crop ends may be used. If this supplementary requirement is specified, the number of tests per pipe shall also be specified. If a specimen from any length fails because of lack of ductility prior to satisfactory completion of the first step of the flattening test requirement, that pipe shall be rejected subject to retreatment in accordance with Specification A 530/A 530M and satisfactory retest. If a specimen from any length of pipe fails because of a lack of soundness, that length shall be rejected, unless subsequent retesting indicates that the remaining length is sound.

S4. Metal Structure and Etching Test

S4.1 The steel shall be homogeneous as shown by etching tests conducted in accordance with the appropriate sections of Method E 381. Etching tests shall be made on a cross section from one end or both ends of each pipe and shall show sound and reasonably uniform material free from injurious laminations, cracks, and similar objectionable defects. If this supplementary requirement is specified, the number of tests per pipe required shall also be specified. If a specimen from any length shows objectionable defects, the length shall be rejected, subject to removal of the defective end and subsequent retests indicating the remainder of the length to be sound and reasonably uniform material.

S5. Carbon Equivalent

S5.1 The steel shall conform to a carbon equivalent (CE) of 0.50 maximum as determined by the following formula:

$$CE = \%C + \frac{\%Mn}{6} + \frac{\%Cr + \%Mo + \%V}{5} + \frac{\%Ni + \%Cu}{15}$$

S5.2 A lower CE maximum may be agreed upon between the purchaser and the producer.

S5.3 The CE shall be reported on the test report.

S6. Heat Treated Test Specimens

S6.1 At the request of the purchaser, one tensile test shall be performed by the manufacturer on a test specimen from each heat of steel furnished which has been either stress relieved at 1250 °F or normalized at 1650 °F, as specified by the purchaser. Other stress relief or annealing temperatures, as appropriate to the analysis, may be specified by agreement between the purchaser and the manufacturer. The results of this test shall meet the requirements of Table 1.

S7. Internal Cleanliness–Government Orders

S7.1 The internal surface of hot finished ferritic steel pipe and tube shall be manufactured to a free of scale condition equivalent to the visual standard listed in SSPC-SP6. Cleaning shall be performed in accordance with a written procedure that has been shown to be effective. This procedure shall be available for audit.

S8. Requirements for Carbon Steel Pipe for Hydrofluoric Acid Alkylation Service

S8.1 Pipe shall be provided in the normalized heat-treated condition.

S8.2 The carbon equivalent (CE), based upon heat analysis, shall not exceed 0.43 % if the specified wall thickness is equal to or less than 1 in. [25.4 mm] or 0.45 % if the specified wall thickness is greater than 1 in. [25.4 mm].

S8.3 The carbon equivalent (CE) shall be determined using the following formula:

$$CE = C + Mn/6 + (Cr + Mo + V)/5 + (Ni + Cu)/15$$

S8.4 Based upon heat analysis in mass percent, the vanadium content shall not exceed 0.02 %, the niobium content shall not exceed 0.02 %, and the sum of the vanadium and niobium contents shall not exceed 0.03 %.

S8.5 Based upon heat analysis in mass percent, the sum of the nickel and copper contents shall not exceed 0.15 %.

S8.6 Based upon heat analysis in mass percent, the carbon content shall not be less than 0.18 %.

S8.7 Welding consumables of repair welds shall be of low hydrogen type. E60XX electrodes shall not be used and the resultant weld chemical composition shall meet the chemical composition requirements specified for the pipe.

S8.8 The designation "HF-N" shall be stamped or marked on each pipe to signify that the pipe complies with this supplementary requirement.

SUMMARY OF CHANGES

Committee A01 has identified the location of selected changes to this specification since the last issue, A 106 – 04a, that may impact the use of this specification. (Approved October 1, 2004)

(*1*) Revised 1.2 to delete the number of Supplementary Requirements.

(*2*) Revised 13.3 to permit the supply of hydrostatically tested or nondestructively tested pipe, and to prohibit the supply of pipe that has failed either test, both when NH pipe has been ordered.

Committee A01 has identified the location of selected changes to this specification since the last issue, A 106 – 04, that may impact the use of this specification. (Approved July 1, 2004)

(*1*) Editorially revised Supplementary Requirements S8.

Committee A01 has identified the location of selected changes to this specification since the last issue, A 106 – 02a, that may impact the use of this specification. (Approved March 1, 2004)

(*1*) Deleted Note 2 in 1.1.
(*2*) Deleted Tables 3 and 4 and renumbered subsequent tables.
(*3*) Deleted Appendixes X1 and X2.
(*4*) Included rationalized SI units throughout, creating a combined standard.
(*5*) Added Supplementary Requirements S8 for HF acid alkylation service.

CERTIFICATE

By Authority Of
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By the Authority Vested By Part 5 of the United States Code § 552(a) and Part 1 of the Code of Regulations § 51 the attached document has been duly INCORPORATED BY REFERENCE and shall be considered legally binding upon all citizens and residents of the United States of America. *HEED THIS NOTICE*: Criminal penalties may apply for noncompliance.

Document Name: ASTM A185: Steel Wire Fabric for Concrete Reinforcement

CFR Section(s): 24 CFR 200, Subpart S

Standards Body: American Society for Testing and Materials

APPROVED

Official Incorporator:
THE EXECUTIVE DIRECTOR
OFFICE OF THE FEDERAL REGISTER
WASHINGTON, D.C.

Standard Specification for WELDED STEEL WIRE FABRIC FOR CONCRETE REINFORCEMENT[1]

This standard is issued under the fixed designation A 185; 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.

1. Scope

1.1 This specification covers welded wire fabric to be used for the reinforcement of concrete.

NOTE 1—The values stated in inch-pound units are to be regarded as the standard.

2. Applicable Documents

2.1 *ASTM Standards*:

A 82 Specification for Cold-Drawn Steel Wire for Concrete Reinforcement[2]

A 700 Recommended Practices for Packaging, Marking, and Loading Methods for Steel Products for Domestic Shipment[2]

2.2 *Military Standard*[3]:

MIL-STD-129 Marking for Shipment and Storage

MIL-STD-163 Steel Mill Products Preparation for Shipment and Storage

2.3 *Federal Standard*[3]:

Fed Std No. 123 Marking for Shipments, Civil Agencies

3. Description of Term

3.1 *Welded Wire Fabric*, as used in this specification, designates a material composed of cold-drawn steel wires, "as drawn" or galvanized, fabricated into sheet (or so-called "mesh") formed by the process of electric welding. The finished material shall consist essentially of a series of longitudinally and transverse wires arranged substantially at right angles to each other and welded together at all points of intersection.

4. Ordering Information

4.1 Orders for material to this specification shall include the following information:

4.1.1 Quantity (weight or square area),

4.1.2 Name of material (welded steel wire fabric for concrete reinforcement),

4.1.3 Wire spacing and sizes,

4.1.4 Length and width of sheets or rolls,

4.1.5 Packaging (see Section 18), and

4.1.6 ASTM designation and date of issue

NOTE 2—A typical ordering description is as follows: 10 000 ft^2 welded steel wire fabric for concrete reinforcement, 4 x 12-W20 x W6, in flat sheets 96 in. wide x 240 in. long, in secured lifts, to ASTM A 185 dated ——.

5. Grade of Wire

5.1 The wire used in the manufacture of welded wire fabrics shall conform to Specification A 82.

6. Fabrication

6.1 The wires shall be assembled by automatic machines or by other suitable mechanical means which will assure accurate spacing and alignment of all members of the finished fabric.

6.2 Longitudinal and transverse members shall be securely connected at every intersection by a process of electrical-resistance welding which employs the principle of fusion combined with pressure.

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[1] This specification is under the jurisdiction of ASTM Committee A-1 on Steel, Stainless Steel and Related Alloy and is the direct responsibility of Subcommittee A01.05 on Steel Reinforcement.

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[2] *Annual Book of ASTM Standards*, Part 4.

[3] Available from Naval Publications and Forms Center, 5801 Tabor Ave., Philadelphia, Pa. 19120.

6.3 Wire of proper grade and quality when fabricated in the manner herein required shall result in a strong, serviceable mesh-type product having substantially square or rectangular openings. It shall be fabricated and finished in a workmanlike manner, shall be free from injurious defects, and shall conform to this specification.

7. Mechanical Requirements

7.1 All wire of the finished fabric shall meet the minimum requirements for tensile properties and shall also withstand the bend test as prescribed for the wire before fabrication in Specification A 82.

7.2 In order to assure adequate weld-shear strength between longitudinal and transverse wires, weld-shear tests as described in 8.3 shall be made. The minimum average shear value in pounds-force shall not be less than 35,000 multiplied by the nominal area of the larger wire in square inches (or in newtons shall not be less than 241 multiplied by the nominal area in square millimetres) where the smaller wire is not less than size W1.2 and has an area of 40 percent or more of the area of the larger wire. Typical examples of the 40 percent or more wire size differential are as follows:

Larger	Smaller
Size No. W20	Size No. W8
Size No. W15	Size No. W6
Size No. W10	Size No. W4

7.3 Fabric having a relationship of longitudinal and transverse wires other than those covered in 7.2 shall not be subject to the weld shear requirement.

8. Tension Tests and Weld Shear Tests

8.1 Tests for determination of conformance to the requirements of 7.1 may be made on the welded wire fabric after fabrication either across or between the welds. Not less than 50 percent of the samples tested shall be across a weld.

8.2 Reduction of area may be determined by measuring the ruptured section of a specimen which has been tested either across or between the welds. However, in the case of a specimen which has been tested across a weld, the measurement shall be made only when rupture has occurred at a sufficient distance from the center of the weld to permit an accurate measurement of the fractured section.

8.3 Weld-shear tests for determination of conformance to the requirements of 7.2 shall be conducted using a fixture as described in Section 11.

8.3.1 Four welds selected at random from a specimen representing the entire width of the fabric shall be tested for weld shear strength. The material shall be deemed to conform to the requirements for weld shear strength if the average of the four samples complies with the values stipulated in 7.2. If this average fails to meet the prescribed minimum value, all the welds across the specimen shall then be tested. The fabric will be acceptable if the average of all weld shear test values across the specimen meets the prescribed minimum value.

9. Bend Tests

9.1 The bend test shall be made on a specimen between the welds.

10. Test Specimens

10.1 Test specimens for testing tensile properties shall be obtained by cutting from the finished fabric, units of suitable size to enable proper performance of the intended tests.

10.2 Specimens used for testing tensile properties across a weld shall have the welded joint located approximately at the center of the wire being tested, and the cross wire forming the welded joint shall extend approximately 1 in. (25 mm) beyond each side of the welded joint.

10.3 Test specimens for determining weld-shear properties shall be obtained by cutting from the finished fabric a section, including one transverse wire, across the entire width of the sheet or roll. From this specimen four welds shall be selected at random for testing. The transverse wire of each test specimen shall extend approximately 1 in. (25 mm) on each side of the longitudinal wire. The longitudinal wire of each test specimen shall be of such length below the transverse wire so as to be adequately engaged by the grips of the testing machine and of such length above the transverse wire that its end shall be above the center line of the upper bearing of the testing device.

10.4 Tests for conformance to dimensional characteristics shall be made on full sheets or rolls.

10.5 If any test specimen shows defects or develops flaws it may be discarded and another substituted.

11. Weld Shear Test Apparatus and Methods

11.1 As the welds in welded wire fabric contribute to the bonding and anchorage value of the wires in concrete, it is imperative that the weld acceptance tests be made in a jig which will stress the weld in a manner similar to which it is stressed in concrete. In order to accomplish this the longitudinal wire in the jig must be stressed in an axis close to its center line. Also the transverse wire must be held closely to the longitudinal wire, and in the same relative position, so as to prevent rotation of the transverse wire.

11.2 Figure 1[4] shows the details of a typical testing jig together with two anvils which make it possible to test welds for wire up to ⅝ in. (15.88 mm) in diameter. This testing jig can be used in most tension testing machines and should be hung in a ball and socket arrangement at the center of the machine. This, or a similarly effective fixture designed on the same principle, is acceptable.

11.3 Test specimens should be inserted through the notch in the anvil using the smallest notch available in which the longitudinal wire will fit loosely. The longitudinal wire shall be in contact with the surface of the free rotating rollers while the transverse wire shall be supported by the anvil on each side of the slot. The bottom jaws of the testing machine shall grip the lower end of the longitudinal wire and the load shall be applied at a rate of stressing not to exceed 100,000 psi/min (689 MPa/min).

12. Number of Tests

12.1 One test for conformance with the provisions of 6.1 shall be made for each 75,000 ft^2 (6968 m^2) of fabric or remaining fraction thereof.

12.2 One specimen for each 300,000 ft^2 (27,870 m^2) of fabric or remaining fraction thereof, and as defined in 10.3 shall be tested for conformance to the requirements of 7.2.

13. Gages, Spacing, and Dimensions

13.1 Gages, spacing, and arrangement of wires, and dimensions of units in flat sheet form or rolls shall conform to the requirements specified by the purchaser.

14. Width of Fabric

14.1 The width of fabric shall be considered to be the center-to-center distance between outside longitudinal wires. The permissible variation shall not exceed ½ in. (13 mm) greater or less than the specified width.

14.2 Transverse wires shall not project beyond the centerline of each longitudinal edge wire more than a distance of 1 in., unless otherwise specified.

14.3 When transverse wires are specified to project a specific length beyond the center line of a longitudinal edge wire, the permissible variation shall not exceed ½ in. (13 mm) greater or less than the specified length; however, the over-all width (total of projection one side plus width plus projection other side) shall not exceed 1 in. (25 mm) greater or less than specified.

15. Permissible Variations in Wire Diameter

15.1 The permissible variation in diameter of any wire in the finished fabric shall conform to the tolerances prescribed for the wire before fabrication in the Specification A 82 with the exception of out-of-round requirements.

16. Spacings

16.1 The average spacing of wires shall be such that the total number of wires contained in a sheet or roll is equal to or greater than that determined by the specific spacing, but the center-to-center distance between individual members may vary not more than ¼ in. (6.35 mm) from the specified spacing. It is understood that sheets of fabric of the same specified length may not always contain an identical number of transverse wires and, therefore, may have various lengths of longitudinal overhand.

17. Overall Dimensions

17.1 The overall length of flat sheets, measured on any wire, may vary ±1 in. (25.4 mm) or 1 percent, whichever is greater.

17.2 In case the width of flat sheets or rolls is specified as the overall width (tip-to-tip length of cross wires), the width shall not be more than ±1 in. (25.4 mm) of the specified width.

18. Rolls or Sheets

18.1 Welded wire fabric shall be furnished

[4] A detailed drawing showing complete dimensions of the testing jig may be obtained at a nominal cost from ASTM Headquarters, 1916 Race St., Philadelphia, Pa. 19103. Request Adjunct No. 12-101850-00.

either in flat sheets or in rolls as specified by the purchaser.

19. Packaging

19.1 When fabric is furnished in flat sheets, it shall be assembled in bundles of convenient size containing not more than 150 sheets and securely fastened together.

19.2 When fabric is furnished in rolls, each roll shall be secured so as to prevent unwinding during shipping and handling.

19.3 When specified in the purchase order, packaging shall be in accordance with the procedures in Recommended Practices A 700.

20. Marking

20.1 Each bundle of flat sheets and each roll shall have attached thereto a suitable tag bearing the name of the manufacturer, description of the material and such other information as may be specified by the purchaser.

20.2 *For Government Procurement Only*—When specified in the contract, material shall be preserved, packaged, and packed in accordance with the requirements of MIL-STD-163. The applicable levels shall be as specified in the contract. Marking for shipment of such material shall be in accordance with Fed. Std. No. 123 for civil agencies and MIL-STD-129 for military agencies.

21. Inspection

21.1 The inspector representing the purchaser shall have free entry at all times while work on the contract of the purchaser is being performed to all parts of the manufacturer's works that concern the manufacture of the material ordered. The manufacturer shall afford the inspector all reasonable facilities to satisfy him that the material is being furnished in accordance with this specification.

21.2 Except for yield strength, all tests and inspection shall be made at the place of manufacture prior to shipment, unless otherwise specified. Such tests shall be so conducted as not to interfere unnecessarily with the operation of the works.

21.3 If the purchaser considers it desirable to determine compliance with the yield strength requirements of Specification A 82, he may have yield strength tests made in a recognized laboratory, or his representative may make the test at the mill if such tests do not interfere unnecessarily with the mill operations.

21.4 *For Government Procurement Only*—Except as otherwise specified in the contract, contractor is responsible for the performance of all inspection and test requirements specified herein. Except as otherwise specified in the contract, the contractor may use his own or any other suitable facilities for the performance of the inspection and test requirements specified herein, unless disapproved by the purchaser at the time of purchase. The purchaser shall have the right to perform any of the inspections and tests at the same frequency as set forth in this specification where such inspections are deemed necessary to assure that material conforms to prescribed requirements.

22. Rejection and Retests

22.1 Material that does not meet the requirements of this specification may be rejected. Unless otherwise specified, any rejection shall be reported to the manufacturer within 5 days from the time of selection of test specimens.

22.2 In case a specimen fails to meet the tension or bend test, the material shall not be rejected until two additional specimens taken from other wires in the same sheet or roll, have been tested. The material shall be considered as meeting this specification in respect to any prescribed tensile property, provided the tested average for the three specimens, including the specimen originally tested, is at least equal to the required minimum for the particular property in question and provided further that none of the three specimens develops less than 80 percent of the required minimum for the tensile property in question. The material shall be considered as meeting this specification in respect to bend test requirements, provided both additional specimens satisfactorily pass the prescribed bend test.

22.3 Any material that shows injurious defects subsequent to its acceptance at the manufacturer's works may be rejected and the manufacturer shall be promptly notified.

22.4 Welded joints shall withstand normal shipping and handling without becoming broken, but the presence of broken welds, regardless of cause, shall not constitute cause for rejection unless the number of broken welds per sheet exceeds 1 percent of the total number of joints in a sheet, or if the material is furnished in rolls, 1 percent of the total number of joints in 150 ft^2 (14 m^2) of fabric and, furthermore, provided not more than one half the permissible maximum number of broken welds are located on any one wire.

22.5 In case rejection is justified, by reason of failure to meet the weld shear requirements, four additional specimens shall be taken from four different sheets or rolls and tested in accordance with 8.3. If the average of all the weld shear tests does not meet the requirement, the material shall be rejected.

22.5.1 In case rejection is justified by reason of failure to meet the requirements for dimensions, the amount of material rejected shall be limited to those individual sheets or rolls which fail to meet this specification. If, however, the total number of sheets or rolls thus rejected exceeds 25 percent of the total number in the shipment, the entire shipment may be rejected.

22.6 Rust, surface seams, or surface irregularities will not be cause for rejection provided the minimum dimensions, cross-sectional area and tensile properties of a hand wirebrushed test specimen are not less than the requirements of this specification.

23. Rehearing

23.1 Rejected materials shall be preserved for a period of at least two weeks from the date of inspection, during which time the manufacturer may make claim for a rehearing and retesting.

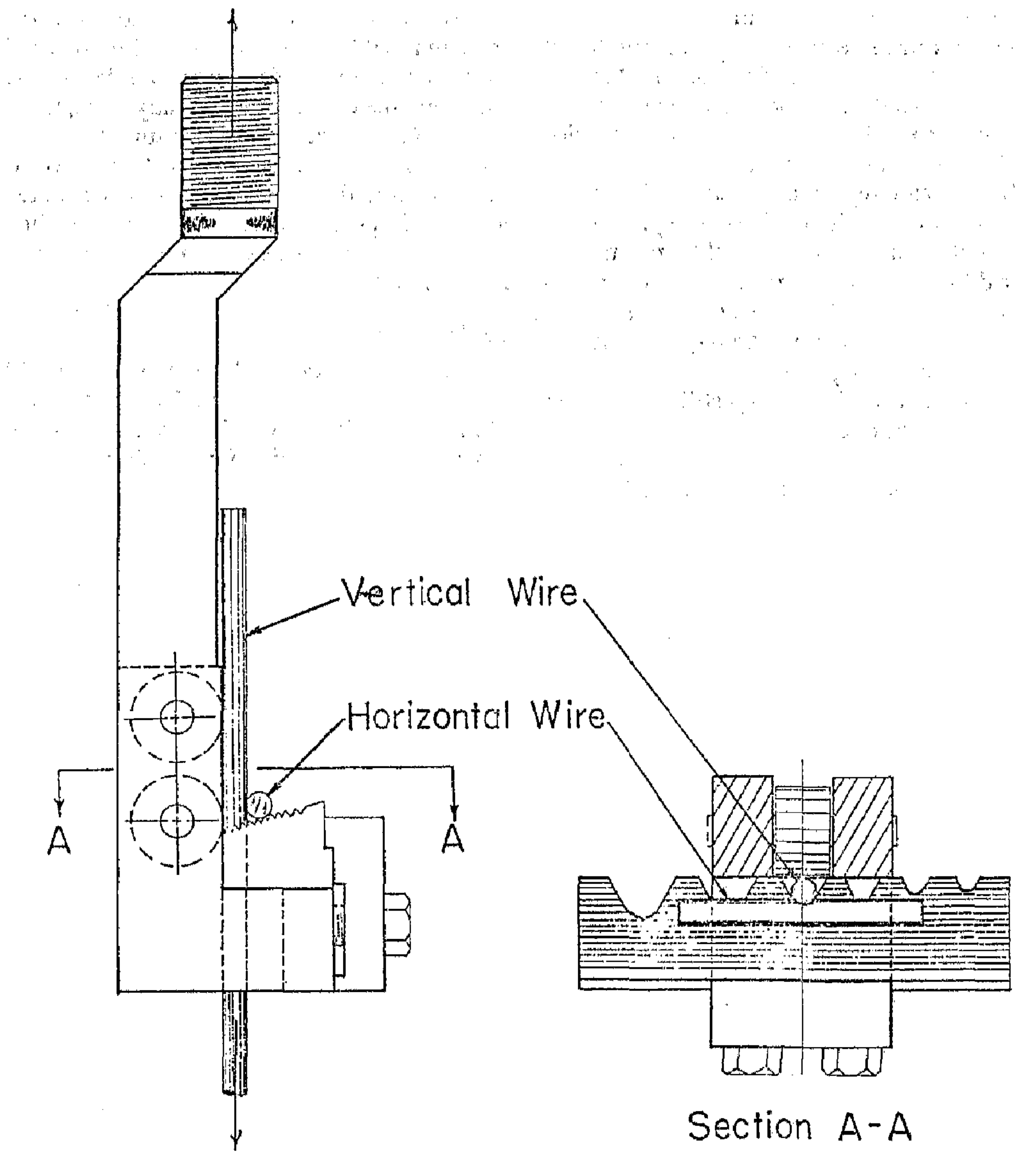

FIG. 1 Welded Wire Fabric Weld Tester.

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Document Name: ASTM A242: Standard Specification for High-Strength Low-Alloy Structural Steel

CFR Section(s): 24 CFR 200, Subpart S

Standards Body: American Society for Testing and Materials

APPROVED

Official Incorporator:
THE EXECUTIVE DIRECTOR
OFFICE OF THE FEDERAL REGISTER
WASHINGTON, D.C.

Standard Specification for
HIGH-STRENGTH LOW-ALLOY STRUCTURAL STEEL[1]

This standard is issued under the fixed designation A 242; 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.

1. Scope

1.1 This specification covers high-strength low-alloy structural steel shapes, plates and bars for welded, riveted, or bolted construction intended primarily for use as structural members where savings in weight or added durability are important. These steels have enhanced atmospheric corrosion resistance of approximately two times that of carbon structural steels with copper (Note 1). Welding technique is of fundamental importance, and it is presupposed that welding procedure will be in accordance with approved methods. This specification is limited to material up to 4 in. (101.6 mm), inclusive, in thickness.

NOTE 1—Two times carbon structural steel with copper is equivalent to four times carbon structural steel without copper (copper 0.02 max).

NOTE 2—The values stated in U.S. customary units are to be regarded as the standard.

2. General Requirements for Delivery

2.1 Material furnished under this specification shall conform to the applicable requirements of the current edition of ASTM Specification A 6, General Requirements for Rolled Steel Plates, Shapes, Sheet Piling, and Bars for Structural Use.[2]

3. Process

3.1 The steel shall be made by one or more of the following processes: open-hearth, basic-oxygen, or electric-furnace.

4. Chemical Requirements

4.1 The heat analysis shall conform to the requirements prescribed in Table 1.

4.2 The steel shall conform on product analysis to the requirements prescribed in Table 1, subject to the product analysis tolerances in Specification A 6.

4.3 Choice and use of alloying elements, combined with carbon, manganese, phosphorus, sulfur, and copper within the limits prescribed in 4.1 to give the mechanical properties prescribed in Section 5 and to provide the atmospheric corrosion resistance of 1.1, shall be made by the manufacturer and included and reported in the heat analysis to identify the type of steel applied. Elements commonly added include: chromium, nickel, silicon, vanadium, titanium, and zirconium.

4.4 When required, the manufacturer shall supply evidence of corrosion resistance satisfactory to the purchaser.

5. Tensile Requirements

5.1 The material as represented by the test specimens shall conform to the requirements as to tensile properties prescribed in Table 2.

5.2 For material under 5/16 in. (7.9 mm) in thickness or diameter, as represented by the test specimen, a deduction of 1.25 percentage points from the percentage of elongation in 8 in. (203.2 mm) specified in Table 2 shall be made for each decrease of 1/32 in. (0.8 mm) of the specified thickness or diameter flow below 5/16 in.

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[1] This specification is under the jurisdiction of ASTM Committee A-1 on Steel, Stainless Steel and Related Alloys, and is the direct responsibility of Subcommittee A01.02 on Structural Steel.

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[2] *Annual Book of ASTM Standards*, Part 4.

SUPPLEMENTARY REQUIREMENTS

Standardized supplementary requirements for use at the option of the purchaser are listed in Specification A 6. Those which are considered suitable for use with this specification are listed below by title.

S2. Product Analysis,
S3. Simulated Post-Weld Heat Treatment of Mechanical Test Coupons,
S5. Charpy V-Notch Impact Test,
S6. Drop Weight Test,
S8. Ultrasonic Examination,
S14. Bend Test, and
S15. Reduction of Area Measurement.

TABLE 1 Chemical Requirements (Heat Analysis)

Element	Composition, %	
	Type 1	Type 2
Carbon, max	0.15	0.20
Manganese, max	1.00	1.35
Phosphorous, max	0.15	0.04
Sulfur, max	0.05	0.05
Copper, min	0.20	0.20[a]

[a] If chromium and silicon contents are each 0.50 min, then the copper 0.20 min requirement does not apply.

TABLE 2 Tensile Requirements

	Plates and Bars[a]			Structural Shapes		
	For Thicknesses ¾ in. (19.1 mm), and under	For Thicknesses over ¾ to 1½ in. (19.1 to 38.1 mm), incl.	For Thicknesses over 1½ to 4 in. (38.1 to 101.6 mm), incl.	Groups 1 and 2	Group 3	Groups 4 and 5
Tensile strength, min, psi (MPa)	70 000 (480)	67 000 (460)	63 000 (435)	70 000 (480)	67 000 (460)	63 000 (435)
Yield point, min, psi (MPa)	50 000 (345)	46 000 (315)	42 000 (290)	50 000 (345)	46 000 (315)	42 000 (290)
Elongation in 8 in. or 200 mm, min, %	18[b, d, e]	18[d, e]	18[d, e]	18[b]	18	18
Elongation in 2 in. or 50 mm, min, %	...	21[e]	21[e]	...	...	21[c]

[a] For plates wider than 24 in. (610 mm), the test specimen is taken in the transverse direction. See 11.2 of Specification A 6.
[b] See 5.2.
[c] For wide flange shapes over 426 lb/ft elongation in 2 in. or 50 mm of 18% minimum applies.
[d] Elongation not required to be determined for floor plate.
[e] For plates wider than 24 in. (610 mm) the elongation requirement is reduced two percentage points.

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This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 1916 Race St., Philadelphia, Pa. 19103, which will schedule a further hearing regarding your comments. Failing satisfaction there, you may appeal to the ASTM Board of Directors.

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Standard Specification for
CARBON STEEL EXTERNALLY THREADED STANDARD FASTENERS[1]

This standard is issued under the fixed designation A 307; 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.

ε NOTE—Table 3, which was incorrectly retained at last revision, was editorially deleted and Table 4 renumbered to Table 3 in November 1979.

1. Scope

1.1 This specification[2] covers the chemical and mechanical requirements of two grades of carbon steel externally threaded standard fasteners, in sizes 1/4 in. (6.35 mm) through 4 in. (104 mm). This specification does not cover requirements for externally threaded fasteners having heads with slotted or recessed drives or for mechanical expansion anchors. The fasteners covered by this specification are frequently used for the following applications:

1.1.1 *Grade A Bolts,* for general applications, and

1.1.2 *Grade B Bolts,* for flanged joints in piping systems where one or both flanges are cast iron.

1.2 If no grade is specified in the inquiry, contract, or order, Grade A bolts shall be furnished.

1.3 Nonheaded anchor bolts, either straight or bent, to be used for structural anchorage purposes, shall conform to the requirements of Specification A 36 with tension tests to be made on the bolt body or on the bar stock used for making the anchor bolts.

1.4 Suitable nuts are covered in Specification A 563. Unless otherwise specified, the grade and style of nut for each grade of fastener, of all surface finishes, shall be as follows:

Fastener Grade and Size	Nut Grade and Style[A]
A, 1/4 to 1 1/2 in.	A, hex
A, over 1 1/2 to 4 in.	A, heavy hex
B, 1/4 to 4 in.	A, heavy hex

[A] Nuts of other grades and styles having specified proof load stresses (Specification A 563, Table 3) greater than the specified grade and style of nut are also suitable.

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

2. Applicable Documents

2.1 *ASTM Standards:*

A 36 Specification for Structural Steel[3]

A 153 Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware[4]

A 370 Methods and Definitions for Mechanical Testing of Steel Products[7]

A 563 Specification for Carbon and Alloy Steel Nuts[5]

B 454 Specification for Mechanically Deposited Coatings of Cadmium and Zinc on Ferrous Metals[6]

2.2 *American National Standards:*[8]

ANSI B1.1 Unified Screw Threads

ANSI B18.2.1 Square and Hex Bolts and Screws

3. Materials and Manufacture

3.1 Steel for bolts shall be made by the open-hearth, basic-oxygen, or electric-furnace process.

[1] This specification is under the jurisdiction of ASTM Committee F-16 on Fasteners, and is the direct responsibility of Subcommittee F 16.02 on Steel Bolting.

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[2] For ASME Boiler and Pressure Vessel Code applications see related Specification SA-307 in Section II of that Code.

[3] *Annual Book of ASTM Standards,* Part 4.

[4] *Annual Book of ASTM Standards,* Part 3.

[5] *Annual Book of ASTM Standards,* Parts 1 and 4.

[6] *Annual Book of ASTM Standards,* Parts 4 and 9.

[7] *Annual Book of ASTM Standards,* Parts 1, 2, 3, 4, 5, and 10.

[8] May be obtained from American National Standards Institute, Inc., 1430 Broadway, New York, N. Y. 10018.

3.2 Bolts may be produced by hot or cold forging of the heads or machining from bar stock.

3.3 Bolt threads may be rolled or cut.

3.4 When specified, galvanized bolts shall be hot-dip zinc coated in accordance with the requirements of Class C of Specification A 153. When specified by the purchaser to be mechanically galvanized, bolts covered by this specification shall be mechanically zinc coated and the coating and coated fasteners shall conform to the requirements for Class 50 of Specification B 454, or to the coating thickness, adherence, and quality requirements for Class C of Specification A 153.

4. Chemical Requirements

4.1 Steel shall conform to the following chemical requirements:

	Grade A Bolts	Grade B Bolts
Phosphorus, max, %	0.06	0.04
Sulfur, max, %	0.15	0.05

4.2 Resulfurized material is not subject to rejection based on product analysis for sulfur.

4.3 Bolts are customarily furnished from stock, in which case individual heats of steel cannot be identified.

4.4 Application of heats of steel to which bismuth, selenium, tellurium, or lead has been intentionally added shall not be permitted for Grade B bolts.

5. Mechanical Requirements

5.1 Bolts shall not exceed the maximum hardness required in Table 1. Bolts less than three diameters in length, or bolts with drilled or undersize heads shall have hardness values not less than the minimum nor more than the maximum hardness limits required in Table 1, as hardness is the only requirement.

5.2 Bolts $1^3/_8$ in. in diameter or less, other than those excepted in 4.1, shall be tested full size and shall conform to the requirements for tensile strength specified in Table 2.

5.3 Bolts larger than $1^3/_8$ in. in diameter, other than those excepted in 4.1, shall preferably be tested full size and when so tested, shall conform to the requirements for tensile strength specified in Table 2. When equipment of sufficient capacity for full-size bolt testing is not available, or when the length of the bolt makes full-size testing impractical, machined specimens shall be tested and shall conform to the requirements shown below:

	Tensile Strength, ksi (MPa)	Elongation in 2 in. or 50 mm, %
Grade A and Grade B bolts	60 (415) min	18 min
Grade B bolts only	100 (690) max	...

In the event that bolts are tested by both full size and by machine test specimen methods, the full-size test shall govern if a controversy between the two methods exists.

5.4 For bolts on which both hardness and tension tests are performed, acceptance based on tensile requirements shall take precedence in the event that there is controversy over low readings of hardness tests.

6. Dimensions

6.1 Unless otherwise specified, threads shall be the Coarse Thread Series as specified in the latest issue of ANSI B1.1, having a Class 2A tolerance.

6.2 Unless otherwise specified, Grade A bolts shall be hex bolts with dimensions as given in the latest issue of ANSI B 18.2.1. Unless otherwise specified, Grade B bolts shall be heavy hex bolts with dimensions as given in the latest issue of ANSI B 18.2.1.

6.3 Unless otherwise specified, bolts to be used with nuts or tapped holes which have been tapped oversize, in accordance with Specification A 563, shall have Class 2A threads before hot dip or mechanical galvanizing. After galvanizing, the maximum limit of pitch and major diameter may exceed the Class 2A limit by the following amount:

Diameter, in.	Oversize Limit, in. (mm)[A]
Up to 7/16, incl	0.016 (0.41)
Over 7/16 to 1, incl	0.021 (0.53)
Over 1	0.031 (0.79)

[A] These values are the same as the minimum overtapping required for galvanized nuts in Specification A 563.

6.4 The gaging limit for bolts shall be verified during manufacture or use by assembly of a nut tapped as nearly as practical to the amount oversize shown above. In case of dispute, a calibrated thread ring gage of that same size (Class X tolerance, gage tolerance plus) shall be used. Assembly of the gage, or the nut described above, must be possible with hand effort following application of light machine oil to prevent galling and damage to the gage. These inspections, when performed to resolve disputes, shall be performed at the frequency and quality described in Table 3.

7. Test Methods

7.1 The material shall be tested in accordance with Supplement III of Methods and A 370.

7.2 Standard square and hexagon bolts only shall be tested by the wedge tension method. Fracture shall be in the body or threads of the bolt without any fracture at the junction of the head and body. Other headed bolts shall be tested by the axial tension method.

7.3 Speed of testing as determined with a free running crosshead shall be a maximum of 1 in. (25.4 mm)/min for the tensile strength tests of bolts.

8. Number of Tests and Retests

8.1 The requirements of this specification shall be met in continuous mass production for stock, and the manufacturer shall make sample inspections to ensure that the product conforms to the specified requirements. Additional tests of individual shipments of material are not ordinarily contemplated. Individual heats of steel are not identified in the finished product.

8.2 When specified in the order, the manufacturer shall furnish a test report certified to be the last completed set of mechanical tests for each stock size in each shipment.

8.3 When additional tests are specified on the purchase order, a lot, for purposes of selecting test samples, shall consist of all material offered for inspection at one time that has the following common characteristics:

8.3.1 One type of item.

8.3.2 One nominal size, and

8.3.3 One nominal length of bolts.

8.4 From each lot, the number of tests for each requirement shall be as follows:

Number of Pieces in Lot	Number of Samples
800 and under	1
801 to 8 000	2
8 001 to 22 000	3
Over 22 000	5

8.5 If any machined test specimen shows defective machining it may be discarded and another specimen substituted.

8.6 Should any sample fail to meet the requirements of a specified test, double the number of samples from the same lot shall be tested, in which case all of the additional samples shall meet the specification.

9. Marking

9.1 Bolt heads shall be marked (by raised or depressed mark at the option of the manufacturer) to identify the manufacturer. The manufacturer may use additional marking for his own use.

10. Inspection

10.1 If the inspection described in 10.2 is required by the purchaser it shall be specified in the inquiry, order, or contract.

10.2 The inspector representing the purchaser shall have free entry, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works that concern the manufacture of the material ordered. The manufacturer shall afford the inspector all reasonable facilities, without charge, to satisfy him that the material is being furnished in accordance with this specification. All tests (except product analysis) and inspection shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

11. Rejection

11.1 Unless otherwise specified, any rejection based on tests specified herein shall be reported to the manufacturer within 30 working days from the receipt of samples by the purchaser.

TABLE 1 Hardness Requirements for Bolts

Bolt Size, in.	Grade	Hardness			
		Brinell		Rockwell B	
		min	max	min	max
All	A	121	241[A]	69	100[A]
	B	121	212	69	95

[A] Except when tested by wedge tension test.

TABLE 2 Tensile Requirements for Full-Size Bolts

Bolt Size, in.	Threads per inch	Stress Area[A] in.^{2}	Tensile Strength, lbf[B]	
			Grades A and B, min[C]	Grade B only, max[D]
1/4	20	0.0318	1 900	3 180
5/16	18	0.0524	3 100	5 240
3/8	16	0.0775	4 650	7 750
7/16	14	0.1063	6 350	10 630
1/2	13	0.1419	8 500	14 190
9/16	12	0.182	11 000	18 200
5/8	11	0.226	13 550	22 600
3/4	10	0.334	20 050	33 400
7/8	9	0.462	27 700	46 200
1	8	0.606	36 350	60 600
1 1/8	7	0.763	45 800	76 300
1 1/4	7	0.969	58 150	96 900
1 3/8	6	1.155	69 300	115 500
1 1/2	6	1.405	84 300	140 500
1 3/4	5	1.90	114 000	190 000
2	4 1/2	2.50	150 000	250 000
2 1/4	4 1/2	3.25	195 000	325 000
2 1/2	4	4.00	240 000	400 000
2 3/4	4	4.93	295 800	493 000
3	4	5.97	358 200	597 000
3 1/4	4	7.10	426 000	710 000
3 1/2	4	8.33	499 800	833 000
3 3/4	4	9.66	579 600	966 000
4	4	11.08	664 800	1 108 000

[A] Area calculated from the formula:

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

where:
A_s = stress area,
D = nominal diameter of bolt, and
n = threads per inch.

[B] 1 lbf = 4.448 N.
[C] Based on 60 ksi (414 MPa).
[D] Based on 100 ksi (689 MPa).

TABLE 3 Sample Sizes and Acceptance Numbers for Inspection of Hot Dip or Mechanically Galvanized Threads

Lot Size	Sample Size[A, B]	Acceptance Number[A]
2 to 90	13	1
91 to 150	20	2
151 to 280	32	3
281 to 500	50	5
501 to 1 200	80	7
1 201 to 3 200	125	10
3 201 to 10 000	200	14
10 001 and over	315	21

[A] Sample sizes of acceptance numbers are extracted from "Single Sampling Plan for Normal Inspection" Table IIA, MIL-STD-105D.
[B] Inspect all bolts in the lot if the lot size is less than the sample size.

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WASHINGTON, D.C.

Standard Specification for HIGH-STRENGTH BOLTS FOR STRUCTURAL STEEL JOINTS[1]

This standard is issued under the fixed designation A 325; 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.

This specification has been approved for use by agencies of the Department of Defense and for listing in the DOD Index of Specifications and Standards.

1. Scope

1.1 This specification[2] covers the chemical and mechanical requirements of various types of quenched and tempered steel bolts commonly known as "high-strength structural bolts," intended for use in structural joints that are covered under requirements of the Specifications for Structural Joints Using ASTM A 325 or A 490 Bolts,[3] issued by the Research Council on Riveted and Bolted Structural Joints of the Engineering Foundation. The various types of bolts covered in this specification are:

1.1.1 *Type 1*—Bolts made of medium-carbon steel, supplied in sizes $^1/_2$ to $1^1/_2$ in., inclusive, in diameter.

1.1.2 *Type 2*—Bolts made from what is generally described as low-carbon martensite steel, supplied in sizes $^1/_2$ to $1^1/_2$ in., inclusive, in diameter.

1.1.3 *Type 3*—Bolts, $^1/_2$ to $1^1/_2$ in., inclusive, in diameter having atmospheric corrosion resistance and weathering characteristics comparable to that of the steels covered in Specification A 588, Specification A 242, and Specification A 709 (these steels have atmospheric corrosion resistance approximately two times that of carbon structural steel with copper).

1.2 When the bolt type is not specified, either Type 1 or Type 2 may be supplied at the option of the manufacturer. Type 3 bolts may be supplied by the manufacturer if agreed by the purchaser. Where elevated temperature applications are involved, Type 1 bolts shall be specified by the purchaser on the order.

1.3 When atmospheric corrosion resistance is required, Type 3 bolts shall be specified by the purchaser in any inquiry or order.

NOTE 1—Bolts for general applications, including anchor bolts, are covered by ASTM Specification A 449, for Quenched and Tempered Steel Bolts and Studs.[4] Also refer to Specification A 449 for quenched and tempered steel bolts and studs with diameters greater than $1^1/_2$ in., but with similar mechanical properties.

1.4 This specification provides that heavy hex structural bolts shall be furnished unless other dimensional requirements are stipulated in the purchase inquiry and order.

1.5 When galvanized high-strength structural bolts are specified, the bolts shall be either Type 1 or 2, at the manufacturer's option, unless otherwise ordered by the purchaser. Bolts shall be hot-dip galvanized, or, with the approval of the purchaser, bolts may be mechanically galvanized. Galvanized bolts and nuts shall be shipped in the same container.

1.6 Suitable nuts are covered in Specification A 563. Unless otherwise specified, nuts shall be heavy hex, and the grade and surface finish of nut for each type of bolt shall be as follows:

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[1] This specification is under the jurisdiction of ASTM Committee F-16 on Fasteners, and is the direct responsibility of Subcommittee F16.02 on Steel Bolts, Nuts, Rivets, and Washers.

Current edition approved May 25, 1979. Published September 1979. Originally published as A 325 – 49 T. Last previous edition A 325 – 78a.

[2] For ASME Boiler and Pressure Vessel Code applications see related Specification SA-325 in Section II of that Code.

[3] Published by American Institute of Steel Construction, New York, N. Y.

[4] *Annual Book of ASTM Standards,* Part 4.

Bolt Type	Nut Grade and Finish
1 and 2, plain (noncoated)	C, plain
1 and 2, galvanized	DH, galvanized
3	C3

1.6.1 Grades 2 and 2H nuts, as specified in Specification A 194, and Grades D and DH nuts, as specified in Specification A 563, are acceptable alternatives for Grade C nuts. Grade 2H nuts, as specified in Specification A 194, are acceptable alternatives for Grade DH nuts. Type DH3 nuts are acceptable alternatives for C3 nuts.

1.7 Suitable hardened washers are covered in Specification F 436. Unless otherwise specified, galvanized washers shall be furnished when galvanized bolts are specified, and Type 3 weathering steel washers shall be furnished when Type 3 bolts are specified.

NOTE 2—A complete metric companion to Specification A 325 has been developed—Specification A 325M; therefore no metric equivalents are presented in this specification.

2. Applicable Documents

2.1 *ASTM Standards:*

A 153 Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware[5]

A 194 Specification for Carbon and Alloy Steel Nuts for Bolts for High-Pressure and High-Temperature Service[6]

A 242 Specification for High-Strength Low-Alloy Structural Steel[4]

A 370 Methods and Definitions for Mechanical Testing of Steel Products[7]

A 490 Specification for Quenched and Tempered Alloy Steel Bolts for Structural Steel Joints[4]

A 563 Specification for Carbon and Alloy Steel Nuts[4,6]

A 588 Specification for High-Strength Low-Alloy Structural Steel with 50,000 psi Minimum Yield Point to 4 in. Thick[4]

A 709 Specification for Structural Steel for Bridges[4]

B 454 Specification for Mechanically Deposited Coatings of Cadmium and Zinc on Ferrous Metals[8]

F 436 Specification for Hardened Steel Washers for Use with High-Strength Bolts[4]

2.2 *American National Standards:*[9]

ANSI B1.1 Unified Screw Threads

ANSI B18.2.1 Square and Hex Bolts and Screws

2.3 *Military Standard:*[10]

MIL-STD-105D Sampling Procedure and Tables for Inspection by Attributes

3. Ordering Information

3.1 Orders for products under this specification shall include the following:

3.1.1 Quantity (number of pieces of bolts and accessories),

3.1.2 Name of products, including accessories such as nuts and washers when desired,

3.1.3 Coating if required (that is, hot dip galvanized, or mechanical galvanized),

3.1.4 Dimensions including nominal bolt diameter and length. For bolts of dimensional requirements other than heavy hex structural bolts (see 1.4) it is normally necessary to specify grip length,

3.1.5 Type of bolt (that is, Type 1, 2 or 3). Note that Type 1 and 2 bolts may be shipped at the manufacturer's option if type has not been specified by the purchaser.

3.1.6 ASTM designation and date of issue, and

3.1.7 Any special requirements.

NOTE 3—Two examples of ordering descriptions follow: (*1*) 1000 pieces, heavy hex structural bolts, each with one hardened washer, ASTM F 436 and one heavy hex nut, ASTM 563 Grade C, hot dip galvanized, 1 by 4, ASTM A 325 dated ____. (*2*) 1000 pieces, heavy hex structural bolts, no nuts or washers, 7/8 by 2 1/4 Type 1, ASTM A 325 dated ____, for hot-dip galvanizing.

4. Materials and Manufacture

4.1 Steel for bolts shall be made by the open-hearth, basic-oxygen, or electric-furnace process.

4.2 Bolts shall be heat treated by quenching in a liquid medium from above the austenitizing temperature and then tempering by reheating to a temperature of at least 800°F.

4.3 Threads of bolts may be cut or rolled.

4.4 Unless otherwise specified, galvanized bolts shall be hot-dip zinc coated in accordance with the requirements for Class C of Specification A 153. When specified by the purchaser to be mechanically galvanized,

[5] *Annual Book of ASTM Standards*, Part 3.
[6] *Annual Book of ASTM Standards*, Part 1.
[7] *Annual Book of ASTM Standards*, Parts 1, 2, 3, 4, 5, and 10.
[8] *Annual Book of ASTM Standards*, Parts 4 and 9.
[9] May be obtained from American National Standards Institute, Inc., 1430 Broadway, New York, N.Y. 10018.
[10] Available from Naval Publications and Forms Center, 5801 Tabor Ave., Philadelphia, Pa. 19120.

bolts shall be mechanically zinc coated and the coating and coated products shall conform to the requirements for Class 50 of Specification B 454, or to the coating thickness, adherence, and quality requirements for Class C of Specification A 153.

4.5 If heat treatment is performed by a subcontractor the heat-treated material shall be returned to the manufacturer for testing.

5. Chemical Requirements

5.1 Type 1 and 2 bolts shall conform to the requirements as to chemical composition prescribed in Table 1.

5.2 Type 3 bolts shall conform to one of the chemical compositions prescribed in Table 2. The selection of the chemical composition, A, B, C, D, E, or F, shall be at the option of the bolt manufacturer.

5.3 Product analyses may be made by the purchaser from finished material representing each lot of bolts. The chemical composition thus determined shall conform to the requirements prescribed in 4.1 or 4.2.

5.4 Application of heats of steel to which bismuth, selenium, tellurium, or lead has been intentionally added shall not be permitted for bolts.

6. Mechanical Requirements

6.1 Bolts shall not exceed the maximum hardness specified in Table 3. Bolts less than three diameters in length shall have hardness values not less than the minimum nor more than the maximum in hardness limits required in Table 3, as hardness is the only requirement.

6.2 Bolts $1^1/_4$ in. in diameter or less, other than those excepted in 6.1, shall be tested full size and shall conform to the tensile strength and either the proof load or alternative proof load requirements specified in Table 4.

6.3 Bolts larger than $1^1/_4$ in. in diameter, other than those excepted in 6.1, shall preferably be tested full size and when so tested shall conform to the tensile strength and either the proof load or alternative proof load requirements specified in Table 4. When equipment of sufficient capacity for full-size testing is not available, or when the length of the bolt makes full-size testing impractical, machined specimens shall be tested and shall conform to the requirements of Table 5. In the event that bolts are tested by both full-size and by the machined test specimen methods, the full-size test shall govern if a controversy between the two methods exists.

6.4 For bolts on which hardness and tension tests are performed, acceptance based on tensile requirements shall take precedence in the event that there is controversy over low readings of hardness tests.

6.5 In addition, when galvanized bolts and nuts are supplied, the bolt/nut assembly shall be tested full size in an assembled joint as specified in 8.5. After the tightening test, the assembly shall show no signs of failure.

6.6 When hot-dip galvanized Type 2 bolts are supplied, they shall be tension tested after galvanizing in accordance with 6.2 or 6.3 depending on the diameter. The number of tests from each lot shall be in accordance with 9.2.4 or 9.3.4.

7. Dimensions

7.1 Bolts with hex heads shall be full-body bolts conforming to the dimensions for heavy hex structural bolts specified in the American National Standard for Square and Hex Bolts and Screws (ANSI B18.2.1).

7.2 Threads shall be the Unified Coarse Thread Series as specified in the American National Standard for Unified Screw Threads (ANSI B1.1), and shall have Class 2A tolerances. When specified, 8 pitch thread series may be used on bolts over 1 in. in diameter.

7.3 Unless otherwise specified, bolts to be used with nuts or tapped holes which have been tapped oversize, in accordance with Specification A 563, shall have Class 2A threads before hot dip or mechanical galvanizing. After galvanizing, the maximum limit of pitch and major diameter may exceed the Class 2A limit by the following amount:

Diameter, in.[A]	Oversize Limit, in.[A]
Up to $^7/_{16}$, incl	0.016
Over $^7/_{16}$ to 1, incl	0.021
Over 1	0.031

[A] These values are the same as the minimum overtapping required for galvanized nuts in Specification A 563.

7.4 The gaging limit for bolts shall be verified during manufacture or use by assembly of a nut tapped as nearly as practical to the amount oversize shown above. In case of dispute, a calibrated thread ring gage of that same size (Class X tolerance, gage tolerance plus) is to be used. Assembly of the gage, or the nut described above, must be possible with hand effort following application of light machine oil to prevent galling and damage to the gage. These inspections, when performed to resolve disputes, are to be performed at the frequency and quality described in Table 6.

8. Test Methods

8.1 Tests shall be conducted in accordance with Supplement III of Methods and Definitions A 370.

8.2 For tension tests a proof load determination is preferred conducted in accordance with Method 1, Length Measurement, of Supplement III of Methods A 370.

8.3 Bolts tested in full size shall be tested in accordance with the wedge test method described in S11.1.5, Supplement III of Methods A 370. Fracture shall be in the body or threads of the bolt, without any fracture at the junction of the head and body.

8.4 The speed of testing as determined with a free-running cross head shall be a maximum of ⅛ in./min for the bolt proof-load determination, and a maximum of 1 in./min for the bolt tensile-strength determination.

8.5 The galvanized bolt shall be placed in a steel joint and assembled with a galvanized washer and a galvanized nut. The joint shall be one or more flat structural steel plates with a total thickness, including the washer, such that 3 to 5 full threads of the bolt are located between the bearing surfaces of the bolt head and nut. The hole in the joint shall have the same nominal diameter as the hole in the washer. The initial tightening of the nut shall produce a load in the bolt not less than 10 % of the specified proof load.[11] After initial tightening, the nut position shall be marked relative to the bolt, and the rotation shown in Table 8 shall be applied. During rotation, the bolt head shall be restrained from turning.

9. Quality Assurance of Mechanical Requirements

9.1 The manufacturer shall make sample inspections of every lot of bolts to ensure that properties of bolts are in conformance with the requirements of this specification. All bolts shall be inspection tested prior to shipment in accordance with one of the two quality assurance procedures described in 9.2 and 9.3, respectively. The manufacturer shall have the option of which procedure will be followed when furnishing bolts to any single purchase order.

9.1.1 The purpose of a lot inspection testing program is to ensure that each lot conforms to the requirements of this specification. For such a plan to be fully effective it is essential that following delivery the purchaser continue to maintain the identification and integrity of each lot until the product is installed in its service application.

9.2 *Production Lot Method:*

9.2.1 All bolts shall be processed in accordance with a lot identification-control quality assurance plan. The manufacturer shall identify and maintain the integrity of each production lot of bolts from raw-material selection through all processing operations and treatments to final packing and shipment. Each lot shall be assigned its own lot-identification number, each lot shall be tested, and the inspection test reports for each lot shall be retained.

9.2.2 A production lot, for purposes of assigning an identification number and from which test samples shall be selected, shall consist of all bolts processed essentially together through all operations to the shipping container that are of the same nominal size, the same nominal length, and produced from the same mill heat of steel.

9.2.3 The manufacturer shall make tests for proof load, tensile strength (wedge test), and hardness of each lot of bolts. Alternatively, in accordance with 6.3, tests may be tensile strength, yield strength, reduction of area, elongation, and hardness.

9.2.4 From each production lot, the minimum number of tests of each required property shall be as follows:

Number of Pieces in Production Lot	Number of Specimens
800 and less	1
801 to 8,000	2
8,001 to 35,000	3
35,001 to 150,000	8
150,001 and over	13

[11] Use of the torque value obtained in a Skidmore-Wilhelm or equivalent calibrator may be used in meeting this requirement.

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9.2.5 If any test specimen shows defective machining it may be discarded and another specimen substituted.

9.2.6 Bolts shall be packed in shipping containers as soon as practicable following final processing. Shipping containers shall be marked with the lot identification number.

9.2.7 A copy of the inspection test report for each production lot from which bolts are supplied to fill the requirements of a shipment shall be furnished to the purchaser when specified in the order. Individual heats of steel need not be identified on the test report.

9.3 *Shipping Lot Method:*

9.3.1 In-process inspection during all manufacturing operations and treatments and storage of manufactured bolts shall be in accordance with the practices of the individual manufacturer.

9.3.2 Before packing bolts for shipment, the manufacturer shall make tests of sample bolts taken at random from each shipping lot. A shipping lot, for purposes of selecting test samples, is defined as that quantity of bolts of the same nominal size and same nominal length necessary to fill the requirements of a single purchase order.

9.3.3 The manufacturer shall make tests for proof load, tensile strength (wedge test), and hardness of each lot of bolts. Alternatively, in accordance with 6.3, tests may be tensile strength, yield strength, reduction of area, elongation, and hardness.

9.3.4 From each shipping lot, the minimum number of tests of each required property shall be as follows:

Number of Pieces in Shipping Lot	Number of Specimens
150 and less	1
151 to 280	2
281 to 500	3
501 to 1,200	5
1,201 to 3,200	8
3,201 to 10,000	13
10,001 and over	20

9.3.5 If any test specimen shows defective machining it may be discarded and another specimen substituted.

9.3.6 A copy of the inspection test report for each shipping lot shall be furnished to the purchaser when specified in the order. Individual heats of steel are not identified in the finished product.

10. Marking

10.1 All bolts, Types 1, 2 and 3, shall be marked A 325 and shall also be marked with a symbol identifying the manufacturer.

10.2 In addition Type 1 bolts may, at the option of the manufacturer be marked with three radial lines 120 deg apart.

10.3 In addition Type 2 bolts shall be marked with three radial lines 60 deg apart.

10.4 In addition Type 3 bolts shall have the A 325 *underlined*, and the manufacturer may add other distinguishing marks indicating that the bolt is atmospheric corrosion resistant and of a weathering type.

10.5 All markings shall be located on the top of the bolt head and may be either raised or depressed, at the option of the manufacturer.

11. Visual Inspection for Head Bursts

11.1 A burst is an open break in the metal (material). Bursts can occur on the flats or corners of the heads of bolts.

11.2 A defective bolt, for the purposes of the visual inspection for bursts, shall be any bolt that contains a burst in the flat of the head which extends into the top crown surface of the head (chamfer circle) or the underhead bearing surface. In addition, bursts occurring at the intersection of two wrenching flats shall not reduce the width across corners below the specified minimum.

11.3 A lot, for the purposes of visual inspection, shall consist of all bolts of one type having the same nominal diameter and length offered for inspection at one time. No lot shall contain more than 10 000 pieces.

11.4 From each lot of bolts, a representative sample shall be picked at random and visually inspected for bursts. The sample size shall be as shown in Table 7. If the number of defective bolts found during inspection by the manufacturer is greater than the acceptance number given in Table 7 for the sample size, all bolts in the lot shall be visually inspected and all defective bolts shall be removed and destroyed. If the number of defective bolts found during inspection by the purchaser is greater than the acceptance number given in Table 7 for the sample size, the lot shall be subject to rejection.

12. Inspection

12.1 If the inspection described in 12.2 is required by the purchaser, it shall be specified in the inquiry and contract or order.

12.2 The inspector representing the purchaser shall have free entry, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works that concern the manufacture of the material ordered. The manufacturer shall afford the inspector all reasonable facilities to satisfy him that the material is being furnished in accordance with this specification. All tests (except product analysis) and inspection shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

13. Rejection

13.1 Unless otherwise specified, any rejection based on tests specified herein shall be reported to the manufacturer within 30 working days from the receipt of samples by the purchaser.

14. Certification

14.1 *Bolts*—When specified on the order the manufacturer shall furnish the test reports described in 9.2.7 or 9.3.6, depending on whether the bolts are furnished by the production lot or shipping lot method.

TABLE 1 Chemical Requirements for Types 1 and 2 Bolts

Element	Composition, %	
	Type 1 Bolts	Type 2 Bolts[A]
Carbon:		
Heat analysis	0.30 min	0.15–0.23
Product analysis	0.27 min	0.13–0.25
Manganese, min:		
Heat analysis	0.50	0.70
Product analysis	0.47	0.67
Phosphorus, max:		
Heat analysis	0.040	0.040
Product analysis	0.048	0.048
Sulfur, max:		
Heat analysis	0.050	0.050
Product analysis	0.058	0.058
Boron, min:		
Heat analysis	...	0.0005
Product analysis	...	0.0005

[A] Type 2 bolts shall be fully killed, fine grain steel.

TABLE 2 Chemical Requirements for Type 3 Bolts

Element	Composition, %					
	Type 3 Bolts[A]					
	A	B	C	D	E	F
Carbon:						
Heat analysis	0.33–0.40	0.38–0.48	0.15–0.25	0.15–0.25	0.20–0.25	0.20–0.25
Product analysis	0.31–0.42	0.36–0.50	0.14–0.26	0.14–0.26	0.18–0.27	0.19–0.26
Manganese:						
Heat analysis	0.90–1.20	0.70–0.90	0.80–1.35	0.40–1.20	0.60–1.00	0.90–1.20
Product analysis	0.86–1.24	0.67–0.93	0.76–1.39	0.36–1.24	0.56–1.04	0.86–1.24
Phosphorus:						
Heat analysis	0.040 max	0.06–0.12	0.035 max	0.040 max	0.040 max	0.040 max
Product analysis	0.045 max	0.06–0.125	0.040 max	0.045 max	0.045 max	0.045 max
Sulfur:						
Heat analysis	0.050 max	0.050 max	0.040 max	0.050 max	0.040 max	0.040 max
Product analysis	0.055 max	0.055 max	0.045 max	0.055 max	0.045 max	0.045 max
Silicon:						
Heat analysis	0.15–0.30	0.30–0.50	0.15–0.30	0.25–0.50	0.15–0.30	0.15–0.30
Product analysis	0.13–0.32	0.25–0.55	0.13–0.32	0.20–0.55	0.13–0.32	0.13–0.32
Copper:						
Heat analysis	0.25–0.45	0.20–0.40	0.20–0.50	0.30–0.50	0.30–0.60	0.20–0.40
Product analysis	0.22–0.48	0.17–0.43	0.17–0.53	0.27–0.53	0.27–0.63	0.17–0.43
Nickel:						
Heat analysis	0.25–0.45	0.50–0.80	0.25–0.50	0.50–0.80	0.30–0.60	0.20–0.40
Product analysis	0.22–0.48	0.47–0.83	0.22–0.53	0.47–0.83	0.27–0.63	0.17–0.43
Chromium:						
Heat analysis	0.45–0.65	0.50–0.75	0.30–0.50	0.50–1.00	0.60–0.90	0.45–0.65
Product analysis	0.42–0.68	0.47–0.83	0.27–0.53	0.45–1.05	0.55–0.95	0.42–0.68
Vanadium:						
Heat analysis	...	...	0.020 min	...	...	...
Product analysis	...	...	0.010 min	...	...	...
Molybdenum:						
Heat analysis	...	0.06 max	...	0.10 max	...	...
Product analysis	...	0.07 max	...	0.11max	...	...
Titanium:						
Heat analysis	...	...	...	0.05 max	...	...
Product analysis	...	...	...	...	...	...

[A] A, B, C, D, E and F are classes of material used for Type 3 bolts. Selection of a class shall be at the option of the bolt manufacturer.

TABLE 3 Hardness Requirements for Bolts

Bolt Size, in.	Hardness Number			
	Brinell		Rockwell C	
	Min	Max	Min	Max
$^1/_2$ to 1, incl	248	331	24	35
$1^1/_8$ to $1^1/_2$, incl	223	293	19	31

TABLE 4 Tensile Requirements for Full Size Bolts

Bolt Size, Threads per Inch and Series Designation	Stress Area,[A] in.^{2}	Tensile Strength[B] min, lbf	Proof Load,[B] Length Measurement Method	Alternative Proof Load,[B] Yield Strength Method, min
Column 1	Column 2	Column 3	Column 4	Column 5
½-13 UNC	0.142	17 050	12 050	13 050
⅝–11 UNC	0.226	27 100	19 200	20 800
¾–10 UNC	0.334	40 100	28 400	30 700
⅞–9 UNC	0.462	55 450	39 250	42 500
1–8 UNC	0.606	72 700	51 500	55 750
1⅛–7 UNC	0.763	80 100	56 450	61 800
1⅛–8 UN	0.790	82 950	58 450	64 000
1¼–7 UNC	0.969	101 700	71 700	78 500
1¼–8 UN	1.000	105 000	74 000	81 000
1⅜–6 UNC	1.155	121 300	85 450	93 550
1⅜–8 UN	1.233	129 500	91 250	99 870
1½–6 UNC	1.405	147 500	104 000	113 800
1½–8 UN	1.492	156 700	110 400	120 850

[A] The stress area is calculated as follows:

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

where:

A_s = stress area, in.^{2},
D = nominal bolt size, and
n = threads per inch.

[B] Loads tabulated are based on the following:

Bolt Size	Column 3	Column 4	Column 5
½, to 1 incl	120 000 psi	85 000 psi	92 000 psi
1⅛ to 1½, incl	105 000 psi	74 000 psi	81 000 psi

TABLE 5 Tensile Requirements for Specimens Machined from Bolts

Bolt Size, in.	Tensile Strength, min, psi	Yield Strength (0.2 % Offset) min, psi	Elongation in 2 in., min, %	Reduction of Area, min, %
1¼, 1⅜ and 1½	105 000	81 000	14	35

TABLE 6 Sample Sizes and Acceptance Numbers for Inspection of Hot Dip or Mechanically Galvanized Threads

Lot Size	Sample Size[A] [B]	Acceptance Number[A]
2 to 90	13	1
91 to 150	20	2
151 to 280	32	3
281 to 500	50	5
501 to 1 200	80	7
1 201 to 3 200	125	10
3 201 to 10 000	200	14
10 001 and over	315	21

[A] Sample sizes of acceptance numbers are extracted from "Single Sampling Plan for Normal Inspection" Table IIA, MIL-STD-105D.
[B] Inspect all bolts in the lot if the lot size is less than the sample size.

TABLE 7 Sample Sizes and Acceptance Numbers for Inspection of Bursts

Lot Size	Sample Size[A, B]	Acceptance Number[A]
1 to 150	5	0
151 to 500	20	1
501 to 1 200	32	2
1 201 to 3 200	50	3
3 201 to 10 000	80	5

[A] Sample sizes and acceptance numbers are extracted from "Single Sampling Plan for Normal Inspection" Table 11A, MIL-STD-105D.

[B] Inspect all bolts in the lot if the lot size is less than the sample size.

TABLE 8 Test for Galvanized Bolts

Bolt Length Diameter, in.	Nominal Nut Rotation, deg (turn)
Up to and including 4	300 (5/6)
Over 4, but not exceeding 8	360 (1)
Over 8	420 (1 1/16)

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Standard Specification for Seamless and Welded Steel Pipe for Low-Temperature Service[1]

This standard is issued under the fixed designation A 333/A 333M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification[2] covers nominal (average) wall seamless and welded carbon and alloy steel pipe intended for use at low temperatures. Several grades of ferritic steel are included as listed in Table 1. Some product sizes may not be available under this specification because heavier wall thicknesses have an adverse affect on low-temperature impact properties.

1.2 Supplementary Requirement S1 of an optional nature is provided. This shall apply only when specified by the purchaser.

1.3 The values stated in either inch-pound units or SI units are to be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification. The inch-pound units shall apply unless the "M" designation of this specification is specified in the order.

NOTE 1—The dimensionless designator NPS (nominal pipe size) has been substituted in this standard for such traditional terms as "nominal diameter," "size," and "nominal size."

2. Referenced Documents

2.1 *ASTM Standards:*

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products[3]

A 530/A 530M Specification for General Requirements for Specialized Carbon and Alloy Steel Pipe[4]

A 671 Specification for Electric-Fusion-Welded Steel Pipe for Atmospheric and Lower Temperatures[4]

E 23 Test Methods for Notched Bar Impact Testing of Metallic Materials[5]

3. General Requirements

3.1 Material furnished to this specification shall conform to the applicable requirements of the current edition of Specification A 530/A 530M unless otherwise provided herein.

4. Ordering Information

4.1 Orders for material under this specification should include the following, as required, to describe the material adequately:

4.1.1 Quantity (feet, centimetres, or number of lengths),

4.1.2 Name of material (seamless or welded pipe),

4.1.3 Grade (Table 1),

4.1.4 Size (NPS or outside diameter and schedule number of average wall thickness),

4.1.5 Length (specific or random), (Section 12) (Permissible Variations in Length Section of Specification A 530/A 530M),

4.1.6 End finish (Ends Section of Specification A 530/A 530M),

4.1.7 Optional requirements, (heat analysis requirement in the Chemical composition Section of A530/A530M; 13.1.1 other temperatures for impact tests; 5.3.4 stress relieving; (see Hydrostatic Test Requirements Section of Specification A 530/A 530M); and 11.6 repair by welding),

4.1.8 Test report required, (Certification Section of Specification A 530/A 530M),

4.1.9 Specification designation, and

4.1.10 Special requirements or exceptions to this specification.

5. Materials and Manufacture

5.1 *Manufacture*—The pipe shall be made by the seamless or welding process with the addition of no filler metal in the welding operation. Grade 4 shall be made by the seamless process.

NOTE 2—For electric-fusion-welded pipe, with filler metal added, see Specification A 671.

5.2 *Heat Treatment:*

5.2.1 All seamless and welded pipe, other than Grades 8 and 11, shall be treated to control their microstructure in accordance with one of the following methods:

5.2.1.1 Normalize by heating to a uniform temperature of not less than 1500°F [815°C] and cool in air or in the cooling chamber of an atmosphere controlled furnace.

5.2.1.2 Normalize as in 5.2.1.1, and, at the discretion of the manufacturer, reheat to a suitable tempering temperature.

5.2.1.3 For the seamless process only, reheat and control hot working and the temperature of the hot-finishing operation to a finishing temperature range from 1550 to 1750°F [845 to 945°C] and cool in a controlled atmosphere furnace from an initial temperature of not less than 1550°F [845°C].

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[1] This specification is under the jurisdiction of ASTM Committee A-1 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.10 on Tubing.

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[2] For ASME Boiler and Pressure Vessel Code applications see related Specification SA-333 in Section II of that Code.

[3] *Annual Book of ASTM Standards*, Vol 01.03.

[4] *Annual Book of ASTM Standards*, Vol 01.01.

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

TABLE 1 Chemical Requirements

Element	Composition, %								
	Grade 1[A]	Grade 3	Grade 4	Grade 6[A]	Grade 7	Grade 8	Grade 9	Grade 10	Grade 11
Carbon, max	0.30	0.19	0.12	0.30	0.19	0.13	0.20	0.20	0.10
Manganese	0.40–1.06	0.31–0.64	0.50–1.05	0.29–1.06	0.90 max	0.90 max	0.40–1.06	1.15–1.50	0.60 max
Phosphorus, max	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.035	0.025
Sulfur, max	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.015	0.025
Silicon	...	0.18–0.37	0.08–0.37	0.10 min	0.13–0.32	0.13–0.32	...	0.10–0.35	0.35 max
Nickel	...	3.18–3.82	0.47–0.98	...	2.03–2.57	8.40–9.60	1.60–2.24	0.25 max	35.0–37.0
Chromium	...	...	0.44–1.01	...	...	...	...	0.15 max	0.50 max
Copper	...	...	0.40–0.75	...	...	...	0.75–1.25	0.15 max	...
Aluminum	...	...	0.04–0.30	...	...	...	...	0.06 max	...
Vanadium, max	...	...	...	...	...	...	...	0.12	...
Columbium, max	...	...	...	...	...	...	...	0.05	...
Molybdenum, max	...	...	...	...	...	...	...	0.05	0.50 max
Cobalt	...	...	...	...	...	...	...	...	0.50 max

[A] For each reduction of 0.01 % carbon below 0.30 %, an increase of 0.05 % manganese above 1.06 % would be permitted to a maximum of 1.35 % manganese.

5.2.1.4 Treat as in 5.2.1.3 and, at the discretion of the manufacturer, reheat to a suitable tempering temperature.

5.2.1.5 Seamless pipe of Grades 1, 6, and 10 may be heat treated by heating to a uniform temperature of not less than 1500°F [815°C], followed by quenching in liquid and reheating to a suitable tempering temperature, in place of any of the other heat treatments provided for in 5.2.1.

5.2.2 Grade 8 pipe shall be heat treated by the manufacturer by either of the following methods:

5.2.2.1 *Quenched and Tempered*—Heat to a uniform temperature of 1475 ± 25°F [800 ± 15°C]; hold at this temperature for a minimum time in the ratio of 1 h/in. [2 min/mm] of thickness, but in no case less than 15 min; quench by immersion in circulating water. Reheat until the pipe attains a uniform temperature within the range from 1050 to 1125°F [565 to 605°C]; hold at this temperature for a minimum time in the ratio of 1 h/in. [2 min/mm] of thickness, but in no case less than 15 min; cool in air or water quench at a rate no less than 300°F [165°C]/h.

5.2.2.2 *Double Normalized and Tempered*—Heat to a uniform temperature of 1650 ± 25°F [900 ± 15°C]; hold at this temperature for a minimum time in the ratio of 1 h/in. [2 min/mm] of thickness, but in no case less than 15 min; cool in air. Reheat until the pipe attains a uniform temperature of 1450 ± 25°F [790 ± 15°C]; hold at this temperature for a minimum time in the ratio of 1 h/in. [2 min/mm] of thickness, but in no case less than 15 min; cool in air. Reheat to a uniform temperature within the range from 1050 to 1125°F [565 to 605°C]; hold at this temperature for a minimum time of 1 h/in. [2 min/mm] of thickness but in no case less than 15 min; cool in air or water quench at a rate not less than 300°F [165°C]/h.

5.2.3 Whether to anneal Grade 11 pipe is per agreement between purchaser and supplier. When Grade 11 pipe is annealed, it shall be normalized in the range of 1400 to 1600°F [760 to 870°C].

5.2.4 Material from which test specimens are obtained shall be in the same condition of heat treatment as the pipe furnished. Material from which specimens are to be taken shall be heat treated prior to preparation of the specimens.

5.2.5 When specified in the order the test specimens shall be taken from full thickness test pieces which have been stress relieved after having been removed from the heat-treated pipe. The test pieces shall be gradually and uniformly heated to the prescribed temperature, held at that temperature for a period of time in accordance with Table 2, and then furnace cooled at a temperature not exceeding 600°F [315°C]. Grade 8 shall be cooled at a minimum rate of 300°F [165°C]/h in air or water to a temperature not exceeding 600°F [315°C].

TABLE 2 Stress Relieving of Test Pieces

Metal Temperature[A, B]				Minimum Holding Time, h/in. [min/mm] of Thickness
Grades 1, 3, 6, 7, and 10		Grade 4[C]		
°F	°C	°F	°C	
1100	600	1150	620	1 [2.4]
1050	565	1100	600	2 [4.7]
1000	540	1050	565	3 [7.1]

[A] For intermediate temperatures, the holding time shall be determined by straight-line interpolation.

[B] Grade 8 shall be stress relieved at 1025 to 1085°F, [550 to 585°C], held for a minimum time of 2 h for thickness up to 1.0 in. [25.4 mm], plus a minimum of 1 h for each additional inch [25.4 mm] of thickness and cooled at a minimum rate of 300°F [165°C]/h in air or water to a temperature not exceeding 600°F [315°C].

[C] Unless otherwise specified, Grade 4 shall be stress relieved at 1150°F [620°C].

6. Chemical Composition

6.1 The steel shall conform to the requirements as to chemical composition prescribed in Table 1.

6.2 When Grades 1, 6, or 10 are ordered under this specification, supplying an alloy grade that specifically requires the addition of any element other than those listed for the ordered grade in Table 1 is not permitted. However, the addition of elements required for the deoxidation of the steel is permitted.

7. Product Analysis

7.1 At the request of the purchaser, an analysis of one billet or two samples of flat-rolled stock from each heat or of two pipes from each lot shall be made by the manufacturer. A lot of pipe shall consist of the following:

NPS Designator	Length of Pipe in Lot
Under 2	400 or fraction thereof
2 to 6	200 or fraction thereof
Over 6	100 or fraction thereof

7.2 The results of these analyses shall be reported to the purchaser or the purchaser's representative and shall conform to the requirements specified.

7.3 If the analysis of one of the tests specified in 7.1 does not conform to the requirements specified, an analysis of each billet or pipe from the same heat or lot may be made, and all billets or pipe conforming to the requirements shall be accepted.

TABLE 3 Tensile Requirements

	Grade 1		Grade 3		Grade 4		Grade 6		Grade 7		Grade 8		Grade 9		Grade 10		Grade 11	
	psi	MPa	psi	MPa	psi	MPa	psi	MPa	psi	MPa	psi	MPa	psi	MPa	psi	MPa	psi	MPa
Tensile strength, min . .	55 000	380	65 000	450	60 000	415	60 000	415	65 000	450	100 000	690	63 000	435	80 000	550	65 000	450
Yield strength, min	30 000	205	35 000	240	35 000	240	35 000	240	35 000	240	75 000	515	46 000	315	65 000	450	35 000	240
	Longitudinal	Transverse	Longitudinal	Transverse	Longitudinal	Transverse	Longitudinal	Transverse	Longitudinal	Transverse	Longitudinal	Transverse	Longitudinal	Transverse	Longitudinal	Transverse	Longitudinal	
Elongation in 2 in. or 50 mm, (or 4D), min, %:																		
Basic minimum elongation for walls 5/16 in. [8 mm] and over in thickness, strip tests, and for all small sizes tested in full section	35	25	30	20	30	16.5	30	16.5	30	22	22	. . .	28	. . .	22	. . .	18[A]	
When standard round 2-in. or 50-mm gage length or proportionally smaller size test specimen with the gage length equal to 4D (4 times the diameter) is used	28	20	22	14	22	12	22	12	22	14	16	. . .	. . .	. . .	16	. . .	. . .	
For strip tests, a deduction for each 1/32 in. [0.8 mm] decrease in wall thickness below 5/16 in. [8 mm] from the basic minimum elongation of the following percentage	1.75[B]	1.25[B]	1.50[B]	1.00[B]	1.50[B]	1.00[B]	1.50[B]	1.00[B]	1.50[B]	1.00[B]	1.25[B]	. . .	1.50[B]	. . .	1.25[B]	. . .	. . .	

[A] Elongation of Grade 11 is for all walls and small sizes tested in full section.
[B] The following table gives the calculated minimum values

Wall Thickness		Elongation in 2 in. or 50 mm, min, %[C]															
		Grade 1		Grade 3		Grade 4		Grade 6		Grade 7		Grade 8		Grade 9		Grade 10	
in.	mm	Longitudinal	Transverse	Longitudinal	Transverse	Longitudinal	Transverse	Longitudinal	Transverse	Longitudinal	Transverse	Longitudinal	Transverse	Longitudinal	Transverse	Longitudinal	Transverse
5/16 (0.312)	8	35	25	30	20	30	16	30	16	30	22	22	. . .	28	. . .	22	. . .
9/32 (0.281)	7.2	33	24	28	19	28	15	28	15	28	21	21	. . .	26	. . .	21	. . .
1/4 (0.250)	6.4	32	23	27	18	27	15	27	15	27	20	20	. . .	25	. . .	20	. . .
7/32 (0.219)	5.6	30	. . .	26	. . .	26	. . .	26	. . .	26	. . .	18	. . .	24	. . .	18	. . .
3/16 (0.188)	4.8	28	. . .	24	. . .	24	. . .	24	. . .	24	. . .	17	. . .	22	. . .	17	. . .
5/32 (0.156)	4	26	. . .	22	. . .	22	. . .	22	. . .	22	. . .	16	. . .	20	. . .	16	. . .
1/8 (0.125)	3.2	25	. . .	21	. . .	21	. . .	21	. . .	21	. . .	15	. . .	19	. . .	15	. . .
3/32 (0.094)	2.4	23	. . .	20	. . .	20	. . .	20	. . .	20	. . .	13	. . .	18	. . .	13	. . .
1/16 (0.062)	1.6	21	. . .	18	. . .	18	. . .	18	. . .	18	. . .	12	. . .	16	. . .	12	. . .

[C] Calculated elongation requirements shall be rounded to the nearest whole number.

NOTE—The preceding table gives the computed minimum elongation values for each 1/32-in. [0.80-mm] decrease in wall thickness. Where the wall thickness lies between two values shown above, the minimum elongation value is determined by the following equation:

Grade	Direction of Test	Equation
1	Longitudinal	$E = 56t + 17.50$ [$E = 2.19t + 17.50$]
	Transverse	$E = 40t + 12.50$ [$E = 1.56t + 12.50$]
3	Longitudinal	$E = 48t + 15.00$ [$E = 1.87t + 15.00$]
	Transverse	$E = 32t + 10.00$ [$E = 1.25t + 10.00$]
4	Longitudinal	$E = 48t + 15.00$ [$E = 1.87t + 15.00$]
	Transverse	$E = 32t + 6.50$ [$E = 1.25t + 6.50$]
6	Longitudinal	$E = 48t + 15.00$ [$E = 1.87t + 15.00$]
	Transverse	$E = 32t + 6.50$ [$E = 1.25t + 6.50$]
7	Longitudinal	$E = 48t + 15.00$ [$E = 1.87t + 15.00$]
	Transverse	$E = 32t + 11.00$ [$E = 1.25t + 11.00$]
8 and 10	Longitudinal	$E = 40t + 9.50$ [$E = 1.56t + 9.50$]
9	Longitudinal	$E = 48t + 13.00$ [$E = 1.87t + 13.00$]

where:
E = elongation in 2 in. or 50 mm, in %, and
t = actual thickness of specimen, in. [mm].

8. Tensile Requirements

8.1 The material shall conform to the requirements as to tensile properties prescribed in Table 3.

9. Impact Requirements

9.1 For Grades 1, 3, 4, 6, 7, 9, and 10, the notched-bar impact properties of each set of three impact specimens, including specimens for the welded joint in welded pipe with wall thicknesses of 0.120 in. [3 mm] and larger, when tested at temperatures in conformance with 14.1 shall be not less than the values prescribed in Table 4. The impact test is not required for Grade 11.

9.1.1 If the impact value of one specimen is below the minimum value, or the impact values of two specimens are less than the minimum average value but not below the minimum value permitted on a single specimen, a retest shall be allowed. The retest shall consist of breaking three additional specimens and each specimen must equal or exceed the required average value. When an erratic result is caused by a defective specimen, or there is uncertainty in test procedures, a retest will be allowed.

9.2 For Grade 8 each of the notched bar impact specimens shall display a lateral expansion opposite the notch of not less than 0.015 in. [0.38 mm].

9.2.1 When the average lateral expansion value for the three impact specimens equals or exceeds 0.015 in. [0.38 mm] and the value for one specimen is below 0.015 in. [0.38 mm] but not below 0.010 in. [0.25 mm], a retest of three additional specimens may be made. The lateral expansion of each of the retest specimens must equal or exceed 0.015 in. [0.38 mm].

9.2.2 Lateral expansion values shall be determined by the procedure in Test Methods and Definitions A 370.

9.2.3 The values of absorbed energy in foot-pounds and the fracture appearance in percentage shear shall be recorded for information. A record of these values shall be retained for a period of at least 2 years.

10. Lengths

10.1 If definite lengths are not required, pipe may be ordered in single random lengths of 16 to 22 ft (Note 3) with 5 % 12 to 16 ft (Note 4), or in double random lengths with a minimum average of 35 ft (Note 4) and a minimum length of 22 ft (Note 4) with 5 % 16 to 22 ft (Note 3).

NOTE 3—This value(s) applies when the inch-pound designation of this specification is the basis of purchase. When the "M" designation of this specification is the basis of purchase, the corresponding metric value(s) shall be agreed upon between the manufacturer and purchaser.

TABLE 4 Impact Requirements for Grades 1, 3, 4, 6, 7, 9, and 10

Size of Specimen, mm	Minimum Average Notched Bar Impact Value of Each Set of Three Specimens[A]		Minimum Notched Bar Impact Value of One Specimen Only of a Set[A]	
	ft·lbf	J	ft·lbf	J
10 by 10	13	18	10	14
10 by 7.5	10	14	8	11
10 by 6.67	9	12	7	9
10 by 5	7	9	5	7
10 by 3.33	5	7	3	4
10 by 2.5	4	5	3	4

[A] Straight line interpolation for intermediate values is permitted.

11. Workmanship, Finish, and Appearance

11.1 The pipe manufacturer shall explore a sufficient number of visual surface imperfections to provide reasonable assurance that they have been properly evaluated with respect to depth. Exploration of all surface imperfections is not required but may be necessary to assure compliance with 11.2.

11.2 Surface imperfections that penetrate more than 12½ % of the nominal wall thickness or encroach on the minimum wall thickness shall be considered defects. Pipe with such defects shall be given one of the following dispositions:

11.2.1 The defect may be removed by grinding provided that the remaining wall thickness is within specified limits.

11.2.2 Repaired in accordance with the repair welding provisions of 11.6.

11.2.3 The section of pipe containing the defect may be cut off within the limits of requirements on length.

11.2.4 The defective pipe may be rejected.

11.3 To provide a workmanlike finish and basis for evaluating conformance with 11.2, the pipe manufacturer shall remove by grinding the following:

11.3.1 Mechanical marks, abrasions and pits, any of which imperfections are deeper than 1/16 in. [1.6 mm], and

11.3.2 Visual imperfections commonly referred to as scabs, seams, laps, tears, or slivers found by exploration in accordance with 11.1 to be deeper than 5 % of the nominal wall thickness.

11.4 At the purchaser's discretion, pipe shall be subject to rejection if surface imperfections acceptable under 11.2 are not scattered, but appear over a large area in excess of what is considered a workmanlike finish. Disposition of such pipe shall be a matter of agreement between the manufacturer and the purchaser.

11.5 When imperfections or defects are removed by grinding, a smooth curved surface shall be maintained, and the wall thickness shall not be decreased below that permitted by this specification. The outside diameter at the point of grinding may be reduced by the amount so removed.

11.5.1 Wall thickness measurements shall be made with a mechanical caliper or with a properly calibrated nondestructive testing device of appropriate accuracy. In case of dispute, the measurement determined by use of the mechanical caliper shall govern.

11.6 Weld repair shall be permitted only subject to the approval of the purchaser and in accordance with Specification A 530/A 530M.

11.7 The finished pipe shall be reasonably straight.

12. Number of Tests Required

12.1 *Transverse or Longitudinal Tensile Test and Flattening Test*—For material heat treated in a batch-type furnace, tests shall be made on 5 % of the pipe from each lot. When heat treated by the continuous process, tests shall be made on a sufficient number of pipe to constitute 5 % of the lot, but in no case less than 2 pipes.

NOTE 4—The term "lot" applies to all pipe of the same nominal size and wall thickness (or schedule) which is produced from the same heat of steel and subjected to the same finishing treatment in a continuous furnace. When final heat treatment is in a batch-type furnace, the lot shall include only that pipe which is heat treated in the same furnace charge.

12.2 *Hydrostatic Test*—Each length of pipe shall be subjected to the hydrostatic test.

12.3 *Impact Test*—One notched bar impact test, consisting of breaking three specimens, shall be made from each heat represented in a heat-treatment load on specimens taken from the finished pipe. This test shall represent only pipe from the same heat and the same heat-treatment load, the wall thicknesses of which do not exceed by more than ¼ in. [6.3 mm] the wall thicknesses of the pipe from which the test specimens are taken. If heat treatment is performed in continuous or batch-type furnaces controlled within a 50°F [30°C] range and equipped with recording pyrometers so that complete records of heat treatment are available, then one test from each heat in a continuous run only shall be required instead of one test from each heat in each heat-treatment load.

12.4 *Impact Tests (Welded Pipe)*—On welded pipe, additional impact tests of the same number as required in 12.3 or 12.4 shall be made to test the weld.

12.5 Specimens showing defects while being machined or prior to testing may be discarded and replacements shall be considered as original specimens.

12.6 Results obtained from these tests shall be reported to the purchaser or his representative.

13. Specimens for Impact Test

13.1 Notched bar impact specimens shall be of the simple beam, Charpy-type, in accordance with Test Methods E 23, Type A with a V notch. Standard specimens 10 by 10 mm in cross section shall be used unless the material to be tested is of insufficient thickness, in which case the largest obtainable subsize specimens shall be used. Charpy specimens of width along the notch larger than 0.394 in. [10 mm] or smaller than 0.099 in. [2.5 mm] are not provided for in this specification.

13.2 Test specimens shall be obtained so that the longitudinal axis of the specimen is parallel to the longitudinal axis of the pipe while the axis of the notch shall be perpendicular to the surface. On wall thicknesses of 1 in. [25 mm] or less, the specimens shall be obtained with their axial plane located at the midpoint; on wall thicknesses over 1 in. [25 mm], the specimens shall be obtained with their axial plane located ½ in. [12.5 mm] from the outer surface.

13.3 When testing welds the specimen shall be, whenever diameter and thickness permit, transverse to the longitudinal axis of the pipe with the notch of the specimen in the welded joint and perpendicular to the surface. When diameter and thickness do not permit obtaining transverse specimens, longitudinal specimens in accordance with 13.2 shall be obtained; the bottom of the notch shall be located at the weld joint.

14. Impact Test

14.1 Except when the size of the finished pipe is insufficient to permit obtaining subsize impact specimens, all material furnished to this specification and marked in accordance with Section 15 shall be tested for impact resistance at the minimum temperature for the respective grades as shown in Table 5.

14.1.1 Special impact tests on individual lots of material may be made at other temperatures as agreed upon between the manufacturer and the purchaser.

14.1.2 When subsize Charpy impact specimens are used and the width along the notch is less than 80 % of the actual wall thickness of the original material, the specified Charpy impact test temperature for Grades 1, 3, 4, 6, 7, 9, and 10 shall be lower than the minimum temperature shown in Table 5 for the respective grade. Under these circumstances the temperature reduction values shall be by an amount equal to the difference (as shown in Table 6) between the temperature reduction corresponding to the actual material thickness and the temperature reduction corresponding to the Charpy specimen width actually tested. Appendix X1 shows some examples of how the temperature reductions are determined.

14.2 The notched bar impact test shall be made in accordance with the procedure for the simple beam, Charpy-type test of Methods E 23.

14.3 Impact tests specified for temperatures lower than 70°F [20°C] should be made with the following precautions. The impact test specimens as well as the handling tongs shall be cooled a sufficient time in a suitable container so that both reach the desired temperature. The temperature shall be measured with thermocouples, thermometers, or any other suitable devices and shall be controlled within 3°F [2°C]. The specimens shall be quickly transferred from the cooling device to the anvil of the Charpy impact testing machine and broken with a time lapse of not more than 5 s.

15. Product Marking

15.1 Except as modified in 15.1.1, in addition to the

TABLE 5 Impact Temperature

Grade	Minimum Impact Test Temperature	
	°F	°C
1	−50	−45
3	−150	−100
4	−150	−100
6	−50	−45
7	−100	−75
8	−320	−195
9	−100	−75
10	−75	−60

TABLE 6 Impact Temperature Reduction

Specimen Width Along Notch or Actual Material Thickness		Temperature Reduction, Degrees Colder[A]	
in.	mm	°F	°C
0.394	10 (standard size)	0	0
0.354	9	0	0
0.315	8	0	0
0.295	7.5 (¾ std. size)	5	3
0.276	7	8	4
0.262	6.67 (⅔ std. size)	10	5
0.236	6	15	8
0.197	5 (½ std. size)	20	11
0.158	4	30	17
0.131	3.33 (⅓ std. size)	35	19
0.118	3	40	22
0.099	2.5 (¼ std. size)	50	28

[A] Straight line interpolation for intermediate values is permitted.

marking prescribed in Specification A 530/A 530M, the marking shall include whether hot finished, cold drawn, seamless or welded, the schedule number and the letters "LT" followed by the temperature at which the impact tests were made, except when a lower test temperature is required because of reduced specimen size, in which case, the higher impact test temperature applicable to a full-size specimen should be marked.

15.1.1 When the size of the finished pipe is insufficient to obtain subsize impact specimens, the marking shall not include the letters LT followed by an indicated test temperature unless Supplementary Requirement S1 is specified.

15.1.2 When the pipe is furnished in the quenched and tempered condition, the marking shall include the letters "QT", and the heat treatment condition shall be reported to the purchaser or his representative.

16. Keywords

16.1 low temperature service; seamless steel pipe; stainless steel pipe; steel pipe; temperature service applications, low

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirement shall apply only when specified by the purchaser in the contract or order.

S1. Subsize Impact Specimens

S1.1 When the size of the finished pipe is insufficient to permit obtaining subsize impact specimens, testing shall be a matter of agreement between the manufacturer and the purchaser.

APPENDIX

(Nonmandatory Information)

X1. DETERMINATION OF TEMPERATURE REDUCTIONS

X1.1 Under the circumstances stated in 14.1.2, the impact test temperatures specified in Table 5 must be lowered. The following examples are offered to describe the application of the provisions of 14.1.2.

X1.1.1 When subsize specimens are used (see 11.1) and the width along the notch of the subsize specimen in 80 % or greater of the actual wall thickness of the original material, the provisions of 14.1.2 do not apply.

X1.1.1.1 For example, if the actual wall thickness of pipe was 0.200 in. [5.0 mm] and the width along the notch of the largest subsize specimen obtainable is 0.160 in. [4 mm] or greater, no reduction in test temperature is required.

X1.1.2 When the width along the subsize specimen notch is less than 80 % of the actual wall thickness of the pipe, the required reduction in test temperature is computed by taking the difference between the temperature reduction values shown in Table 6 for the actual pipe thickness and the specimen width used.

X1.1.2.1 For example, if the pipe were 0.262 in. [6.67 mm] thick and the width along the Charpy specimen notch was 3.33 mm (1/3 standard size), the test temperature would have to be lowered by 25°F [14°C]. That is, the temperature reduction corresponding to the subsize specimen is 35°F [19°C]; the temperature reduction corresponding to the actual pipe thickness is 10°F [5°C]; the difference between these two values is the required reduction in test temperature.

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Standard Specification for STRUCTURAL STEEL[1]

This standard is issued under the fixed designation A 36; 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.

[ε]NOTE—Supplementary Requirement S5 was added editorially in August 1979.

This specification has been approved for use by agencies of the Department of Defense for listing in the DoD Index of Specifications and Standards.

1. Scope

1.1 This specification[2] covers carbon steel shapes, plates, and bars of structural quality for use in riveted, bolted, or welded construction of bridges and buildings, and for general structural purposes. When the steel is used in welded construction, welding procedure shall be suitable for the steel and the intended service.

1.2 Supplemental requirements are provided where improved notch toughness is important. These shall apply only when specified by the purchaser in the order.

NOTE—The values stated in inch-pound units are to regarded as the standard.

2. Appurtenant Materials

2.1 Unless otherwise provided in the order, the current edition of the specifications of the American Society for Testing and Materials listed in Table 1 shall govern the delivery of otherwise unspecified appurtenant materials when included with material purchased under this specification. Unless otherwise specified, all plain and threaded bars used for anchorage purposes shall be subjected to mechanical tests and shall conform to the tensile requirements of Section 7; headed bolts used for anchorage purposes, and all nuts, shall conform to the requirements of Specification A 307, for Carbon Steel Externally and Internally Threaded Standard Fasteners.[3]

3. General Requirements for Delivery

3.1 Material furnished under this specification shall conform to the applicable requirements of the current edition of Specification A 6, for General Requirements for Rolled Steel Plates, Shapes, Sheet Piling, and Bars for Structural Use.[3]

4. Bearing Plates

4.1 Unless otherwise specified, plates used as bearing plates for bridges shall be subjected to mechanical tests and shall conform to the tensile requirements of Section 7.

4.2 Unless otherwise specified, mechanical tests shall not be required for plates over 1½ in. (38 mm) in thickness used as bearing plates in structures other than bridges, subject to the requirement that they shall contain 0.20 to 0.33% carbon by heat analysis, that the chemical composition shall conform to the requirements of Table 2 in phosphorus and sulfur content, and that a sufficient discard shall be made from each ingot to secure sound plates.

5. Process

5.1 The steel shall be made by one or more of the following processes: open-hearth, basic-oxygen, or electric-furnace.

5.2 No rimmed or capped steel shall be used

[1] This specification is under the jurisdiction of ASTM Committee A-1 on Steel, Stainless Steel and Related Alloys, and is the direct responsibility of Subcommittee A01.02 on Structural Steel.

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[2] For ASME Boiler and Pressure Vessel Code Applications see related Specifications SA-36 in Section II of that Code.

[3] *Annual Book of ASTM Standards*, Part 4.

for plates and bars over ½ in. (13 mm) thick or for shapes other than Group 1.

6. Chemical Requirements

6.1 The heat analysis shall conform to the requirements prescribed in Table 2, except as specified in 4.2.

6.2 The steel shall conform on product analysis to the requirements prescribed in Table 2, subject to the product analysis tolerances in Specification A 6, except as specified in 6.3.

6.3 Product analysis is not applicable for bar-size shapes or flat bars ½ in. (13 mm) and under in thickness.

6.4 When tension tests are waived in accordance with 7.2, chemistry consistent with the requirements in Table 2, and with the mechanical properties desired must be applied.

7. Tensile Requirements

7.1 The material as represented by the test specimen, except as specified in 4.2 and 7.2, shall conform to the requirements as to the tensile properties prescribed in Table 3.

7.2 Shapes less than 1 in.^{2} (645 mm^2) in cross section and bars, other than flats, less than ½ in. (13 mm) in thickness or diameter need not be subjected to tension tests by the manufacturer.

7.3 For material under $\frac{5}{16}$ in. (8 mm) in thickness or diameter, a deduction from the percentage of elongation in 8 in. (203 mm), specified in Table 3, of 1.25% shall be made for each decrease of $\frac{1}{32}$ in. (0.8 mm) of the specified thickness or diameter below $\frac{5}{16}$ in.

SUPPLEMENTARY REQUIREMENTS

These requirements shall not apply unless specified in the order.

Standardized supplementary requirements for use at the option of the purchaser are listed in Specification A 6. Those which are considered suitable for use with this specification are listed below by title.

S5. Charpy V-Notch Impact Test.

S14. Bend Test.

ADDED SUPPLEMENTARY REQUIREMENTS

In addition, the following optional supplementary requirements are also suitable for use with this specification.

S1. The material supplied shall be other than rimmed or capped steel.

S2. The material to be supplied shall be silicon-killed fine-grain practice.

TABLE 1 Material Specifications

Material	ASTM Designation[a]
Plate to be bent or formed cold	A 283, Grade C[b]
Steel rivets	A 502, Grade 1[b]
Bolts and nuts	A 307[b], A 325
Cast steel	A 27, Grade 65–35[b]
Forgings (carbon steel)	A 668, Class D
Hot-rolled sheets	A 570, Grade D
Hot-rolled strip	A 570, Grade D
Cold-formed tubing	A 500, Grade B
Hot-formed tubing	A 501

[a] These designations refer to the following specifications of the American Society for Testing and Materials:

A 283, Low and Intermediate Tensile Strength Carbon Steel Plates of Structural Quality,[3]

A 502, Steel Structural Rivets,[3]

A 307, Carbon Steel Externally and Internally Threaded Standard Fasteners,[3]

A 325, High-Strength Bolts for Structural Steel Joints Including Suitable Nuts and Plain Hardened Washers,[3]

A 27, Mild- to Medium-Strength Carbon-Steel Castings for General Application,[4]

A 668, Steel Forgings, Carbon and Alloy, for General Industrial Use,[5]

A 570, Hot-Rolled Carbon Steel Sheet and Strip, Structural Quality,[3]

A 500, Cold-Formed Welded and Seamless Carbon Steel Structural Tubing in Rounds and Shapes,[3] and

A 501, Hot-Formed Welded and Seamless Carbon Steel Structural Tubing.[3]

[b] These have lower yield point than A 36 steel.

[4] *Annual Book of ASTM Standards*, Part 2.
[5] *Annual Book of ASTM Standards*, Part 5.

TABLE 2 Chemical Requirements

Product	Shapes[a]	Plates					Bars			
Thickness, in. (mm)	All	To 3/4 (19), incl.	Over 3/4 to 1½ (19 to 38), incl.	Over 1½ to 2½ (38 to 64), incl.	Over 2½ to 4 (64 to 102), incl.	Over 4 (102)	To 3/4 (19), incl.	Over 3/4 to 1½ (19 to 38), incl.	Over 1½ to 4 (102), incl.	Over 4 (102)
Carbon, max, %	0.26	0.25	0.25	0.26	0.27	0.29	0.26	0.27	0.28	0.29
Manganese, %	...	...	0.80–1.20	0.80–1.20	0.85–1.20	0.85–1.20	...	0.60–0.90	0.60–0.90	0.60–0.90
Phosphorus, max, %	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Sulfur, max, %	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Silicon, %	...	...	...	0.15–0.40	0.15–0.40	0.15–0.40	...	...	...	...
Copper, min, % when copper steel is specified	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20

[a] Manganese content of 0.85–1.35 % and silicon content of 0.15–0.40 % is required for shapes over 426 lb/ft.

TABLE 3 Tensile Requirements[a]

Plates, Shapes,[b] and Bars:	
Tensile strength, psi (MPa)	58 000–80 000 (400–550)
Yield point, min, psi (MPa)	36 000 (250)[c]
Plates and Bars[e,f]:	
Elongation in 8 in. or 200 mm, min, %	20[d]
Elongation in 2 in. or 50 mm, min, %	23
Shapes:	
Elongation in 8 in. or 200 mm, min, %	20[d]
Elongation in 2 in. or 50 mm, min, %	21[b]

[a] For plates wider than 24 in. (610 mm), the test specimen is taken in the transverse direction. See 11.2 of Specification A 6.

[b] For wide flange shapes over 426 lb/ft tensile strength minimum of 58 000 psi (400 MPa) only and elongation in 2 in. of 19 % minimum applies.

[c] Yield point 32 000 psi (220 MPa) for plates over 8 in. in thickness.

[d] See 7.3.

[e] Elongation not required to be determined for floor plate.

[f] For plates wider than 24 in. (610 mm), the elongation requirement is reduced two percentage points.

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Standard Specification for Carbon Structural Steel[1]

This standard is issued under the fixed designation A 36/A 36M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

ϵ^1 NOTE—Table 2 was editorially corrected in September 1999.

1. Scope

1.1 This specification[2] covers carbon steel shapes, plates, and bars of structural quality for use in riveted, bolted, or welded construction of bridges and buildings, and for general structural purposes.

1.2 Supplementary requirements are provided for use where additional testing or additional restrictions are required by the purchaser. Such requirements apply only when specified in the purchase order.

1.3 When the steel is to be welded, a welding procedure suitable for the grade of steel and intended use or service is to be utilized. See Appendix X3 of Specification A 6/A 6M for information on weldability.

1.4 For Group 4 and 5 wide flange shapes for use in tension, it is recommended that the purchaser consider specifying supplementary requirements, such as fine austenitic grain size and Charpy V-Notch Impact testing.

1.5 The values stated in either inch-pound units or SI units are to be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system is to be used independently of the other, without combining values in any way.

1.6 The text of this specification contains notes or footnotes, or both, that provide explanatory material. Such notes and footnotes, excluding those in tables and figures, do not contain any mandatory requirements.

1.7 For plates cut from coiled product, the additional requirements, including additional testing requirements and the reporting of additional test results, of A 6/A 6M apply.

2. Referenced Documents

2.1 *ASTM Standards:*

A 6/A 6M Specification for General Requirements for Rolled Structural Steel Bars, Plates, Shapes, and Sheet Piling[3]

A 27/A 27M Specification for Steel Castings, Carbon, for General Application[4]

A 307 Specification for Carbon Steel Bolts and Studs, 60 000 psi Tensile Strength[5]

A 325 Specification for Structural Bolts, Steel, Heat Treated, 120/105 ksi Minimum Tensile Strength[5]

A 325M Specification for High-Strength Bolts for Structural Steel Joints [Metric][5]

A 500 Specification for Cold-Formed Welded and Seamless Carbon Steel Structural Tubing in Rounds and Shapes[6]

A 501 Specification for Hot-Formed Welded and Seamless Carbon Steel Structural Tubing[6]

A 502 Specification for Steel Structural Rivets[5]

A 563 Specification for Carbon and Alloy Steel Nuts[5]

A 563M Specification for Carbon and Alloy Steel Nuts [Metric][5]

A 570/A 570M Specification for Steel, Sheet and Strip, Carbon, Hot-Rolled, Structural Quality[7]

A 668 Specification for Steel Forgings, Carbon and Alloy, for General Industrial Use[8]

F 568M Specification for Carbon and Alloy Steel Externally Threaded Metric Fasteners[5]

3. Appurtenant Materials

3.1 When components of a steel structure are identified with this ASTM designation but the product form is not listed in the scope of this specification, the material shall conform to one of the standards listed in Table 1 unless otherwise specified by the purchaser.

4. General Requirements for Delivery

4.1 Material furnished under this specification shall conform to the requirements of the current edition of Specification A 6/A 6M, for the ordered material, unless a conflict exists in

[1] This specification is under the jurisdiction of ASTM Committee A-1 on Steel, Stainless Steel, and Related Alloys, and is the direct responsibility of Subcommittee A01.02 on Structural Steel for Bridges, Buildings, Rolling Stock, and Ships.

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[2] For ASME Boiler and Pressure Vessel Code Applications, see related Specifications SA-36 in Section II of that Code.

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

[4] *Annual Book of ASTM Standards*, Vol 01.02.

[5] *Annual Book of ASTM Standards*, Vol 15.08.

[6] *Annual Book of ASTM Standards*, Vol 01.01.

[7] *Annual Book of ASTM Standards*, Vol 01.03.

[8] *Annual Book of ASTM Standards*, Vol 01.05.

TABLE 1 Appurtenant Material Specifications

NOTE 1—The specifier should be satisfied of the suitability of these materials for the intended application. Composition and/or mechanical properties may be different than specified in A 36/A 36M.

Material	ASTM Designation
Steel rivets	A 502, Grade 1
Bolts	A 307, Grade A or F 568M, Class 4.6
High-strength bolts	A 325 or A 325M
Steel nuts	A 563 or A 563M
Cast steel	A 27/A 27M, Grade 65–35 [450–240]
Forgings (carbon steel)	A 668, Class D
Hot-rolled sheets and strip	A 570/A 570M, Grade 36
Cold-formed tubing	A 500, Grade B
Hot-formed tubing	A 501
Anchor bolts	F 1554

which case this specification shall prevail.

4.1.1 Coiled product is excluded from qualification to this specification until levelled and cut to length. Plates produced from coil means plates that have been cut to individual lengths from a coiled product and are furnished without heat treatment. The processor decoils, levels, cuts to length and marks the product. The processor is responsible for performing and certifying all tests, examinations, repairs, inspections or operations not intended to affect the properties of the material. For plates produced from coils, two test results shall be reported for each qualifying coil. See Note 1.

NOTE 1—Additional requirements regarding plate from coil are described in Specification A 6/A 6M.

5. Bearing Plates

5.1 Unless otherwise specified, plates used as bearing plates for bridges shall be subjected to mechanical tests and shall conform to the tensile requirements of Section 8.

5.2 Unless otherwise specified, mechanical tests shall not be required for plates over 1½ in. [40 mm] in thickness used as bearing plates in structures other than bridges, subject to the requirement that they shall contain 0.20 to 0.33 % carbon by heat analysis, that the chemical composition shall conform to the requirements of Table 2 in phosphorus and sulfur content, and that a sufficient discard shall be made to secure sound plates.

6. Process

6.1 The steel shall be made by one or more of the following processes: open-hearth, basic-oxygen, or electric-furnace.

6.2 No rimmed or capped steel shall be used for plates and bars over ½ in. [12.5 mm] thick or for shapes other than Group 1.

7. Chemical Requirements

7.1 The heat analysis shall conform to the requirements prescribed in Table 2, except as specified in 5.2.

7.2 The steel shall conform on product analysis to the requirements prescribed in Table 2, subject to the product analysis tolerances in Specification A 6/A 6M.

8. Tensile Requirements

8.1 The material as represented by the test specimen, except as specified in 5.2 and 8.2, shall conform to the requirements as to the tensile properties prescribed in Table 3.

8.2 Shapes less than 1 in.^{2}[645 mm ^{2}] in cross section and bars, other than flats, less than ½ in. [12.5 mm] in thickness or diameter need not be subjected to tension tests by the manufacturer, provided that the chemical composition used is appropriate for obtaining the tensile properties in Table 3.

TABLE 2 Chemical Requirements

NOTE 1— Where "..." appears in this table there is no requirement. The heat analysis for manganese shall be determined and reported as described in the heat analysis section of Specification A 6/A 6M.

Product	Shapes[A]	Plates[B]					Bars			
Thickness, in. [mm]	All	To ¾ [20], incl	Over ¾ to 1½ [20 to 40], incl	Over 1½ to 2 ½ [40 to 65], incl	Over 2½ to 4 [65 to 100], incl	Over 4 [100]	To ¾ [20], incl	Over ¾ to 1½ [20 to 40], incl	Over 1½ to 4 [100], incl	Over 4 [100]
Carbon, max, %	0.26	0.25	0.25	0.26	0.27	0.29	0.26	0.27	0.28	0.29
Manganese, %	...	...	0.80–1.20	0.80–1.20	0.85–1.20	0.85–1.20	...	0.60–0.90	0.60–0.90	0.60–0.90
Phosphorus, max, %	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Sulfur, max, %	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Silicon, %	0.40 max	0.40 max	0.40 max	0.15–0.40	0.15–0.40	0.15–0.40	0.40 max	0.40 max	0.40 max	0.40 max
Copper, min, % when copper steel is specified	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20

[A] Manganese content of 0.85–1.35 % and silicon content of 0.15–0.40 % is required for shapes over 426 lb/ft [634 kg/m].

[B] For each reduction of 0.01 % below the specified carbon maximum, an increase of 0.06 % manganese above the specified maximum will be permitted up to the maximum of 1.35 %.

TABLE 3 Tensile Requirements[A]

Plates, Shapes,[B] and Bars:	
Tensile strength, ksi [MPa]	58–80 [400–550]
Yield point, min, ksi [MPa]	36 [250][C]
Plates and Bars[D,E]:	
Elongation in 8 in. [200 mm], min, %	20
Elongation in 2 in. [50 mm], min, %	23
Shapes:	
Elongation in 8 in. [200 mm], min, %	20
Elongation in 2 in. [50 mm], min, %	21[B]

[A] See Specimen Orientation under the Tension Tests section of Specification A 6/A 6M.

[B] For wide flange shapes over 426 lb/ft [634 kg/m], the 80 ksi [550 MPa] maximum tensile strength does not apply and a minimum elongation in 2 in. [50 mm] of 19 %, applies.

[C] Yield point 32 ksi [220 MPa] for plates over 8 in. [200 mm] in thickness.

[D] Elongation not required to be determined for floor plate.

[E] For plates wider than 24 in. [600 mm], the elongation requirement is reduced two percentage points. See elongation requirement adjustments under the Tension Tests section of Specification A 6/A 6M.

9. Keywords

9.1 bars; bolted construction; bridges; buildings; carbon; plates; riveted construction; shapes; steel; structural steel; welded construction

SUPPLEMENTARY REQUIREMENTS

These requirements shall not apply unless specified in the order.

Standardized supplementary requirements for use at the option of the purchaser are listed in Specification A 6/A 6M. Those that are considered suitable for use with this specification are listed by title:

S5. Charpy V-Notch Impact Test.

S14. Bend Test.

ADDITIONAL SUPPLEMENTARY REQUIREMENTS

In addition, the following optional supplementary requirements are also suitable for use with this specification.

S91. Fine Austenitic Grain Size

S91.1 The steel shall be killed and have a fine austenitic grain size.

S97. Limitation on Rimmed or Capped Steel

S97.1 The steel shall be other than rimmed or capped.

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Document Name: ASTM A369: Standard Specification for Carbon and Ferritic Alloy Steel Forged and Bored Pipe for High-Temperature Service

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Official Incorporator:
THE EXECUTIVE DIRECTOR
OFFICE OF THE FEDERAL REGISTER
WASHINGTON, D.C.

Designation: A 369/A 369M – 92

Standard Specification for Carbon and Ferritic Alloy Steel Forged and Bored Pipe for High-Temperature Service[1]

This standard is issued under the fixed designation A 369/A 369M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification[2] covers heavy-wall carbon and alloy steel pipe (Note 1) made from turned and bored forgings and is intended for high-temperature service. Pipe ordered under this specification shall be suitable for bending and other forming operations and for fusion welding. Selection will depend on design, service conditions, mechanical properties and high-temperature characteristics.

NOTE 1—The use of the word "pipe" throughout the several sections of this specification is used in the broad sense and intended to mean pipe headers, or leads.

NOTE 2—The dimensionless designator NPS (nominal pipe size) has been substituted in this standard for such traditional terms as "nominal diameter," "size," and "nominal size."

1.2 Several grades of ferritic steels are covered. Their compositions are given in Table 1.

1.3 Supplementary requirements (S1 to S6) of an optional nature are provided. These supplementary requirements call for additional tests to be made, and when desired shall be so stated in the order, together with the number of such tests required.

1.4 The values stated in either inch-pound units or SI units are to be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification. The inch-pound units shall apply unless the "M" designation of this specification is specified in the order.

2. Referenced Documents

2.1 *ASTM Standards:*

A 530/A 530M Specification for General Requirements for Specialized Carbon and Alloy Steel Pipe[3]

E 290 Test Method for Semi-Guided Bend Test for Ductility of Metallic Materials[4]

E 381 Method of Macroetch Testing, Inspection, and Rating Steel Products, Comprising Bars, Billets, Blooms, and Forgings[4]

2.2 *ASME Boiler and Pressure Vessel Code:*

Section IX Welding Qualifications[5]

2.3 *ANSI Standard:*

B46.1 Surface Texture[6]

3. General Requirements

3.1 Material furnished under this specification shall conform to the applicable requirements of the current edition of Specification A 530/A 530M, unless otherwise provided herein.

4. Ordering Information

4.1 Orders for material to this specification should include the following, as required, to describe the desired material adequately:

4.1.1 Quantity (feet, centimetres, or number of lengths),

4.1.2 Name of material (forged and bored pipe),

4.1.3 Grade (Table 1),

4.1.4 Size (inside diameter and minimum wall thickness),

4.1.5 Length (Permissible Variations in Length Section of Specification A 530/A 530M),

4.1.6 End finish (Section 12),

4.1.7 Optional requirements (Sections 8, Supplementary Requirements S1 to S6; 13.2),

4.1.8 Test report required (Certification Section of Specification A 530/A 530M),

4.1.9 Specification designation, and

4.1.10 Special requirements or exceptions to this specification.

5. Materials and Manufacture

5.1 *Discard:*

5.1.1 A sufficient discard shall be made from each ingot to secure freedom from injurious defects. The steel shall have a homogeneous structure.

5.2 *Manufacture:*

5.2.1 Material for forging shall consist of ingots or of blooms, billets, or solid-rolled bars forged or rolled from an ingot, and cut to the required length by a process that will not produce injurious defects in the forging.

5.2.2 The material shall be forged (Note 3) by hammering or pressing, and shall be brought as nearly as practicable to the finished shape and size by hot working.

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[1] This specification is under the jurisdiction of ASTM Committee A-1 on Steel, Stainless Steel, and Related Alloys, and is the direct responsibility of Subcommittee A01.10 on Tubing.

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[2] For ASME Boiler and Pressure Vessel Code applications see related Specification SA-369 in Section II of that Code.

[3] *Annual Book of ASTM Standards*, Vol 01.01.

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

[5] Available from American Society of Mechanical Engineers, 345 E. 47th St., New York, NY 10017.

[6] Available from American National Standards Institute, 11 West 42nd St., 13th Floor, New York, NY 10036.

NOTE 3—The cross-sectional area of the solid forging shall have a reduction by forging or by rolling and forging from that of the ingot in the ratio of not less than 3 to 1.

5.2.3 Unless otherwise specified, the final forging operation shall be followed by a treatment suitable to the grade as specified in 5.4.

5.3 *Machining:*

5.3.1 All forgings shall have both the inner and outer surfaces machined.

5.3.2 After heat treatment, the pipe shall be machined to a finish with a roughness value no greater than 250-μin. [6.4-μm] arithmetical average deviation (AA), terms as defined in ANSI B46.1-1962, unless otherwise specified.

5.4 *Heat Treatment:*

5.4.1 All pipe of the grades shown in Table 1 other than FPA, FPB, FP1, FP2, FP12, and FP91 shall be reheated and furnished in the full-annealed or normalized and tempered condition. If furnished in the normalized and tempered condition (Note 4), the temperature for tempering shall be 1250°F [680°C] or higher for Grades FP5, FP9, FP21, and FP22, and 1200°F [650°C] or higher for Grades FP36 and FP11.

NOTE 4—It is recommended that the temperature for tempering should be at least 100°F [50°C] above the intended service temperature; consequently, the purchaser should advise the manufacturer if the service temperature is to be over 1100°F [600°C].

5.4.2 Pipe in Grades FPA and FPB as a final heat treatment shall be either normalized or shall be given a stress relieving treatment at 1200 to 1300°F [650 to 705°C]. Pipe in Grades FP1, FP2, and FP12, as a final heat treatment shall be given a stress-relieving treatment at 1200 to 1300°F [650 to 705°C].

NOTE 5—Certain of the ferritic steels covered by this specification tend to harden if cooled rapidly from above their critical temperature. Some will air harden, that is, become hardened to an undesirable degree when cooled in air from high temperatures. Therefore, operations involving heating such steels above their critical temperatures, such as welding, hot-bending and other forming operations, should be followed by suitable heat treatment.

5.4.3 Except when Supplementary S6 is specified by the purchaser, Grade FP91 shall be normalized and tempered by reheating within the temperature range of 1900 to 2000°F [1040 to 1095°C], followed by air cooling and tempering at a sub-critical temperature of 1350°F [730°C] minimum.

6. Chemical Composition

6.1 The steel shall conform to the requirements as to chemical composition prescribed in Table 1.

7. Heat Analysis

7.1 An analysis of each heat of steel shall be made by the steel manufacturer to determine the percentages of the elements specified. If secondary melting processes are employed, the heat analysis shall be obtained from one remelted ingot or the product of one remelted ingot of each primary melt. The chemical composition thus determined, or that determined from a product analysis made by the tubular product manufacturer, shall conform to the requirements specified.

7.2 In the case of large ingots poured from two or more heats, the weighted average of the chemical determinations of the several heats, made in accordance with 7.1, shall conform to the requirements specified in Section 6.

TABLE 1 Chemical Requirements

	Composition, %			
Grade	FPA	FPB	FP1	FP2
Carbon	0.25 max	0.30 max	0.10–0.20	0.10–0.20
Manganese	0.27–0.93	0.29–1.06	0.30–0.80	0.30–0.61
Phosphorus, max	0.035	0.035	0.025	0.025
Sulfur, max	0.035	0.035	0.025	0.025
Silicon	0.10 min	0.10 min	0.10–0.50	0.10–0.30
Chromium	...	...	...	0.50–0.81
Molybdenum	...	...	0.44–0.65	0.44–0.65
Grade	FP5	FP9	FP11	FP12
Carbon	0.15 max	0.15 max	0.05–0.15	0.05–0.15
Manganese	0.30–0.60	0.30–0.60	0.30–0.60	0.30–0.61
Phosphorus, max	0.025	0.030	0.025	0.025
Sulfur, max	0.025	0.030	0.025	0.025
Silicon	0.50 max	0.50–1.00	0.50–1.00	0.50 max
Chromium	4.00–6.00	8.00–10.00	1.00–1.50	0.80–1.25
Molybdenum	0.45–0.65	0.90–1.10	0.44–0.65	0.44–0.65
Grade	FP21	FP22	FP91	
Carbon	0.05–0.15	0.05–0.15	0.08–0.12	
Manganese	0.30–0.60	0.30–0.60	0.30–0.60	
Phosphorus, max	0.025	0.025	0.025	
Sulfur, max	0.025	0.025	0.025	
Silicon	0.50 max	0.50 max	0.20–0.50	
Chromium	2.65–3.35	1.90–2.60	8.00–9.50	
Molybdenum	0.80–1.06	0.87–1.13	0.85–1.05	
			Others:	
			Ni 0.40 max	
			V 0.18–0.25	
			Cb 0.06–0.10	
			N 0.03–0.07	
			A1 0.04 max	

TABLE 2 Tensile Requirements

Grade	FPA	FPB	FP1, FP2	FP12	FP91	All Others
Tensile strength, min; ksi [MPa]	48 [330]	60 [415]	55 [380]	60 [415]	85 [585]	60 [415]
Yield strength, min; ksi [MPa]	30 [210]	35 [240]	30 [210]	32 [220]	60 [415]	30 [210]

Grade	Elongation Requirements							
	FPA		FPB		FP91		All Others	
	Longitudinal	Transverse	Longitudinal	Transverse	Longitudinal	Transverse	Longitudinal	Transverse
Elongation in 2 in. or 50 mm, min, %:								
Basic minimum elongation for wall 5⁄16 in. [8 mm] and over in thickness, strip tests, and for all small sizes tested in full-section	35	25	30	17	27	18	30	20
When standard round 2-in. or 50-mm gage length test specimen is used	28	20	22	12	20	13	22	14

8. Product Analysis

8.1 At the request of the purchaser, a product analysis shall be made by the manufacturer on every heat.

8.2 The results of these analyses shall be reported to the purchaser or his representative, and shall conform to the requirements specified in Section 6.

8.3 If the analysis of one of the tests specified in Section 7 or 8 does not conform to the requirements specified in Section 6 an analysis of each billet or pipe from the same heat may be made, and all billets or pipes conforming to the requirements shall be accepted.

9. Tensile Requirements

9.1 The material shall conform to the requirements as to tensile properties prescribed in Table 2. Tests for acceptance shall be made after final heat treatment of the forging.

10. Mechanical Tests Required

10.1 *Transverse or Longitudinal Tension Test*—One test shall be made on a specimen from one end of one length of pipe representing each heat in each heat-treatment lot.

10.2 *Flattening Test*—For pipe NPS 14 or less, and diameter to wall thickness ratios of more than 7.0, a flattening test shall be carried out in accordance with Specification A 530/A 530M. A test shall be carried out on a specimen taken from one end of each length of pipe.

10.3 *Bend Test*—For pipe larger than NPS 14 or NPS where diameters to wall thickness ratio is 7.0 or less, a bend test shall be carried out in accordance with Test Method E 290. Unless otherwise specified, the test specimens shall be taken in a transverse direction. The diameter of the pin shall be $\frac{2}{3}t$ for longitudinal specimens or $1\frac{1}{3}t$ for transverse specimens, where t is the specimen thickness. The bend test specimens shall be bent at room temperature through 180° without cracking. One bend test shall be taken from one end of each length of pipe.

11. Workmanship

11.1 The pipe shall conform to the sizes and shapes specified by the purchaser.

12. Ends

12.1 Pipe ends shall be machined as specified in the purchase order.

13. Finish

13.1 The finished pipe shall be reasonably straight and shall have a workmanlike finish.

13.2 Repair of defects by welding shall be permitted only subject to the approval of the purchaser. Defects shall be thoroughly chipped or ground out before welding. Only qualified operators and procedures in accordance with the ASME Boiler and Pressure Vessel Code, Section IX, shall be used. Local or full heat treatment in accordance with 5.4 shall follow welding. Local grinding following welding and retreating shall be considered as meeting the requirements of 5.3.

14. Product Marking

14.1 In addition to the marking prescribed in Specification A 530/A 530M, the marking shall include the wall thickness, piece mark, length, and additional symbol "S" if the pipe conforms to the supplementary requirements specified in Supplementary Requirements S1 to S5, and the heat number or the manufacturer's number by which the heat can be identified. Indentation stamping, instead of stenciling, will be permitted only with the written approval of the purchaser.

SUPPLEMENTARY REQUIREMENTS

One or more of the following supplementary requirements shall apply only when specified in the purchase order. The purchaser may specify a different frequency of test or analysis than is provided in the supplementary requirement. Subject to agreement between the purchaser and manufacturer, retest and retreatment provisions of these supplementary requirements may also be modified.

S1. Additional Tension Test

S1.1 An additional tension test shall be made on a specimen from one or each end of each pipe. If this supplementary requirement is specified, the number of tests per pipe required shall be specified. If a specimen from any length fails to meet the required tensile properties (tensile, yield, and elongation), that length shall be rejected subject to retreatment in accordance with Specification A 530/A 530M and satisfactory retest.

S2. Additional Flattening or Bend Tests

S2.1 The appropriate flattening or bend test may be made on specimens from both ends of each length of pipe. Crop ends may be used. If the specimen from either end of any length fails to conform to the specific requirement, that length shall be rejected.

S3. Ultrasonic Tests

S3.1 Each pipe shall be ultrasonically tested to determine its soundness throughout the entire length of the pipe. Until suitable standards are established, the basis for rejection of material shall be a matter of agreement between the manufacturer and purchaser.

S4. Hydrostatic Test

S4.1 A hydrostatic pressure test shall be applied as agreed upon by the manufacturer and purchaser.

S5. Metal Structure and Etching Tests

S5.1 The steel shall be homogeneous as shown by etching tests conducted in accordance with the appropriate portions of Method E 381. Etching tests shall be made on a cross section from one end or both ends of each pipe and shall show sound and reasonably uniform material free of injurious laminations, cracks, and similar objectionable defects. If this supplementary requirement is specified, the number of tests per pipe required shall also be specified. If a specimen from any length shows objectionable defects, the length shall be rejected, subject to removal of the defective end and subsequent retests indicating the remainder of the length to be sound and reasonably uniform material.

S6. Alternative Heat Treatment—Grade FP91

S6.1 Grade FP91 shall be normalized in accordance with 5.5.3 and tempered at a temperature, to be specified by the purchaser, less than 1350°F [730°C]. It shall be the purchaser's responsibility to subsequently temper at 1350°F [730°C] minimum. All mechanical tests shall be made on material heat treated in accordance with 5.4.3. The certification shall reference this supplementary requirement indicating the tempering temperature applied. The notation "S6" shall be included with the required marking of the pipe.

CERTIFICATE

By Authority Of
THE UNITED STATES OF AMERICA
Legally Binding Document

By the Authority Vested By Part 5 of the United States Code § 552(a) and Part 1 of the Code of Regulations § 51 the attached document has been duly INCORPORATED BY REFERENCE and shall be considered legally binding upon all citizens and residents of the United States of America. *HEED THIS NOTICE*: Criminal penalties may apply for noncompliance.

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An American National Standard
American Association State Highway and
Transportation Officials Standard
AASHTO No.: T 244

Standard Methods and Definitions for
MECHANICAL TESTING OF STEEL PRODUCTS[1]

[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]

[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.

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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:

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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)
¾ and ½	6 (150)
⅜ and ¼	4 (100)
⅛	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 ⅜ 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 1½ 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 $1^1/_2$ in. (38 mm) in diameter which require machined tests shall use a standard $^1/_2$-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 $1^1/_2$ in. and over in diameter, a standard $^1/_2$-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 ½ in. by 2 in. and 1½ 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:

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

[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_0 = 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: 15N Scale, 15-kgf Load, Diamond Penetrator	Rockwell Superficial Hardness: 30N Scale 30-kgf Load, Diamond Penetrator	Rockwell Superficial Hardness: 45N Scale, 45-kgf Load, Diamond Penetrator	Approximate Tensile Strength, ksi (MPa)
68	940	...	...	920	85.6	93.2	84.4	75.4	...
67	900	...	...	895	85.0	92.9	83.6	74.2	...
66	865	...	...	870	84.5	92.5	82.8	73.3	...
65	832	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: 15N Scale, 15-kgf Load, Diamond Penetrator	Rockwell Superficial Hardness: 30N Scale 30-kgf Load, Diamond Penetrator	Rockwell Superficial Hardness: 45N Scale, 45-kgf Load, Diamond Penetrator	Approximate Tensile Strength, ksi (MPa)
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[A] (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 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)
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.
⅝ to 1½ (16 to 38), excl	Up to 1½ (38), incl	Full section by 8-in. gage length or machine standard ½ by 2-in. (13 by 51-mm) gage length specimen from center of section (Fig. 5).	Mill reduced section to 2-in. (51-mm) gage length and approximately 25 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 ⅝	Full section by 8-in. (203-mm) gage length or machine to sub-size specimen (Fig. 5).	Machine to sub-size specimen (Fig. 5).
⅝ to 1½ (16 to 38), excl	Full section by 8-in. (203-mm) gage length or machine standard ½ in. by 2-in. (13 by 51-mm) gage length specimen from center of section (Fig. 5).	Machine standard ½ in. by 2-in. gage length specimen from center of section (Fig. 5).
1½ (38) and over	Full section by 8-in. (203-mm) gage length or machine standard ½ in. by 2-in. (13 by 51-mm) gage length specimen from midway between surface and center of section (Fig. 5).	Machine standard ½ in. by 2-in. (13 by 51-mm gage length specimen from midway between surface and center of section (Fig. 5).

Other Bar-Size Sections

All sizes	Full section by 8-in. (203-mm) gage length or prepare test specimen 1½ in. (38 mm) wide (if possible) by 8-in. (203-mm) gage length.	Mill reduced section to 2-in. (51-mm) gage length and approximately 25 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.

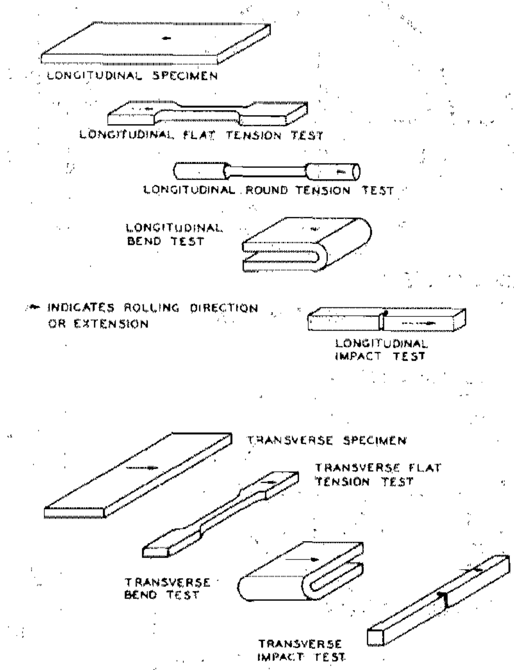
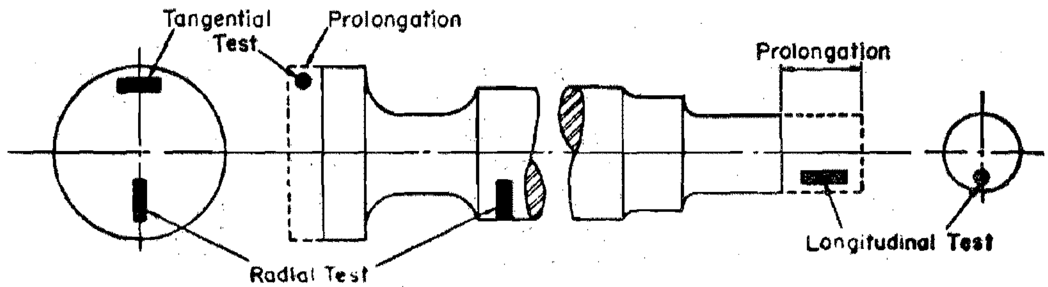
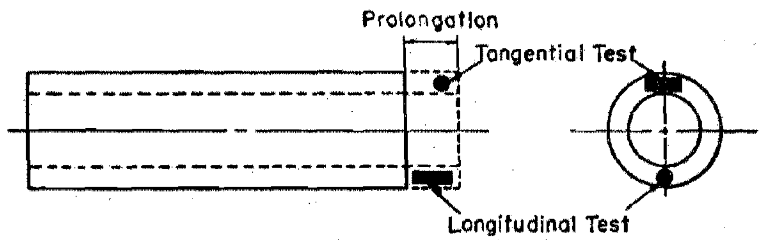


FIG. 1 The Relation of Test Coupons and Test Specimens to Rolling Direction or Extension (Applicable to General Wrought Products).

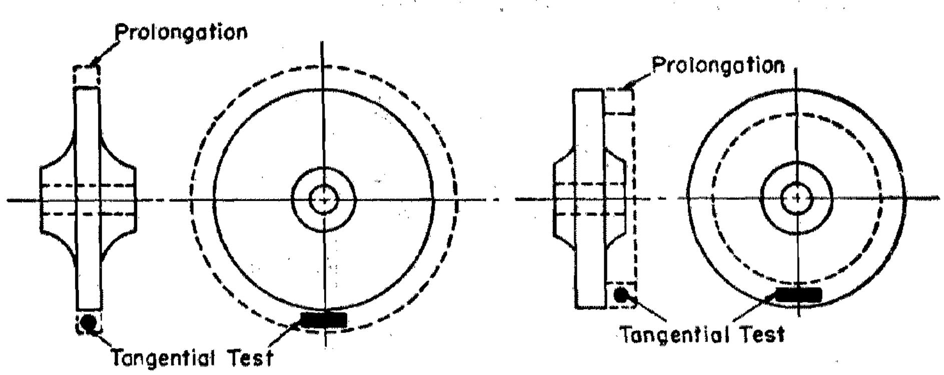
PRO_00086146



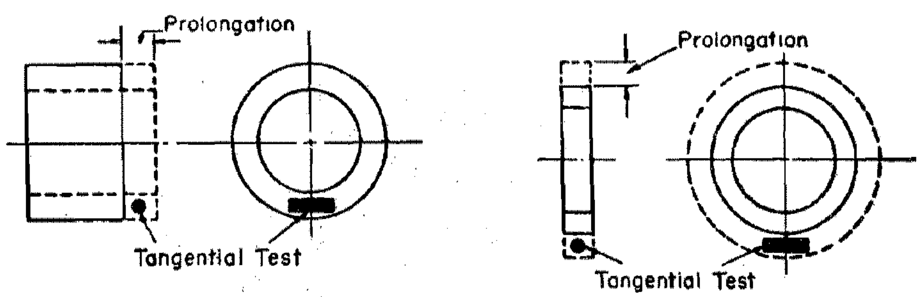
(*a*) **Shafts and Rotors**



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

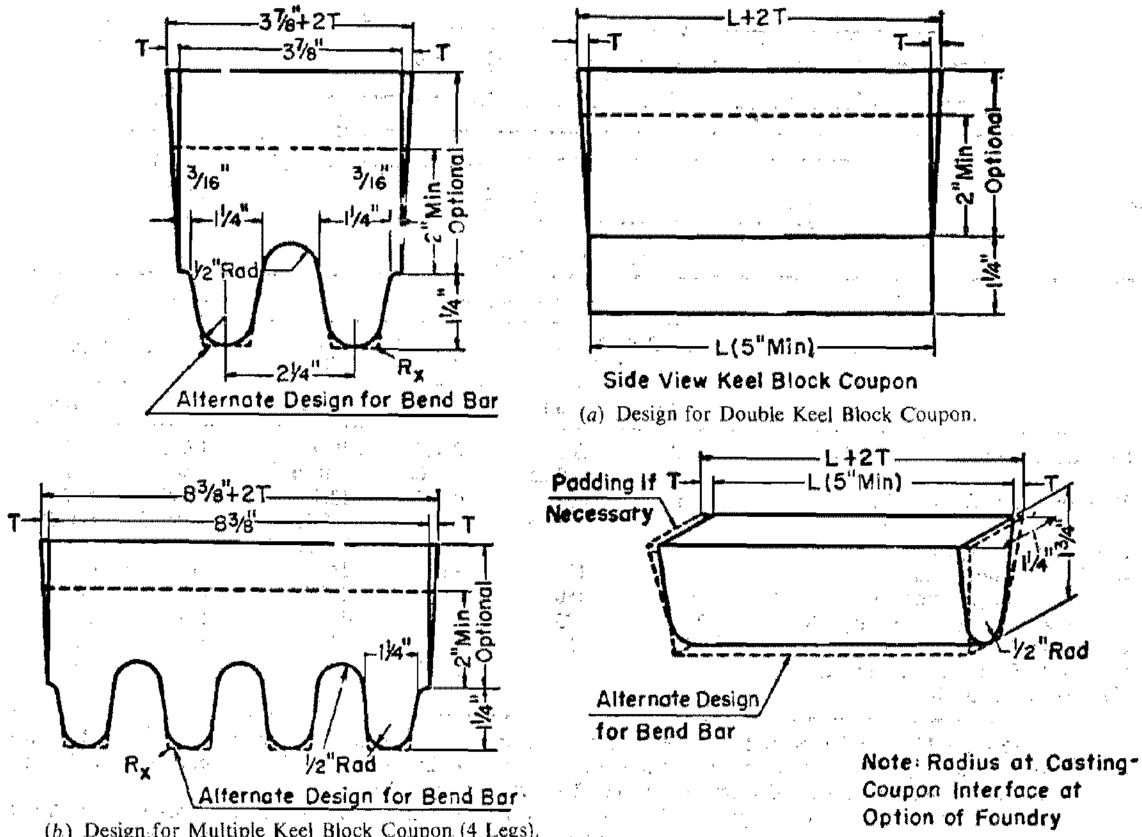


(*c*) **Disk Forgings**



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

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



(*a*) Design for Double Keel Block Coupon.

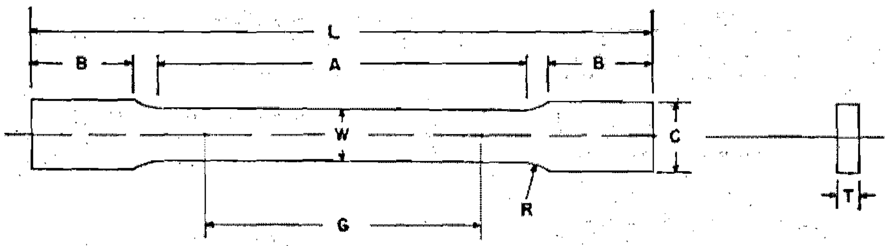
(*b*) Design for Multiple Keel Block Coupon (4 Legs).

(*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.

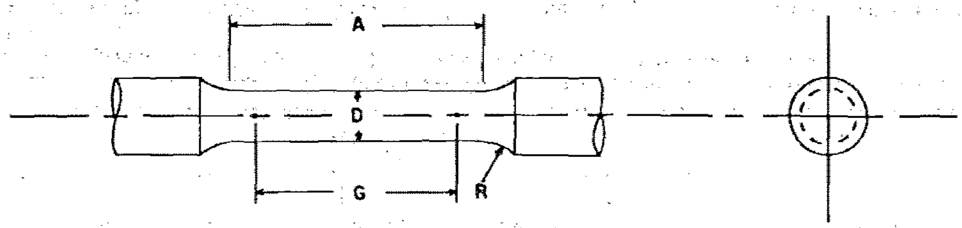
NOTE 7—To aid in obtaining axial loading during testing of ¼-in. (6-mm) wide specimens, the over-all length should be as the material will permit.

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
D—Diameter (Note 1)	0.500 ± 0.010	12.5 ± 0.25	0.350 ± 0.007	8.75 ± 0.18	0.250 ± 0.005	6.25 ± 0.12	0.160 ± 0.003	4.00 ± 0.08	0.113 ± 0.002	2.50 ± 0.05
R—Radius of fillet, min	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.

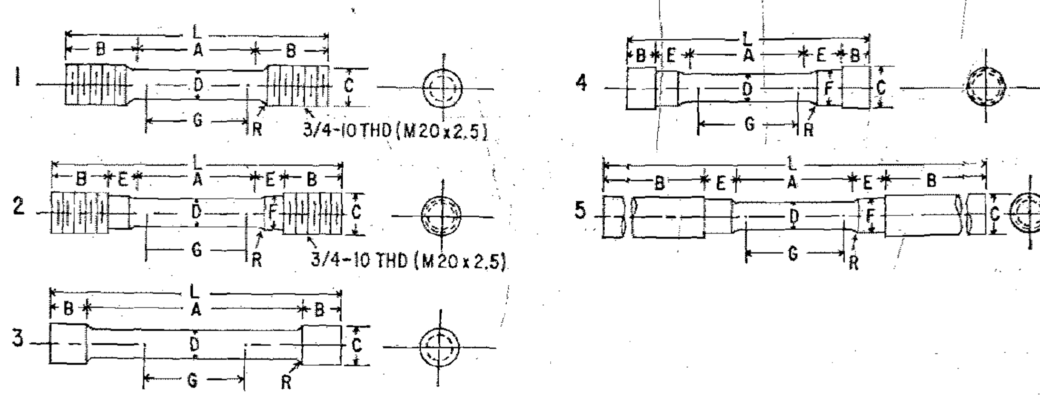
NOTE 3—The gage length and fillets shall be as shown, but the ends may be of any form to fit the holders of the testing machine in such a way that the load shall be axial (see Fig. 9). If the ends are to be held in wedge grips it is desirable, if possible, to make the length of the grip section great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

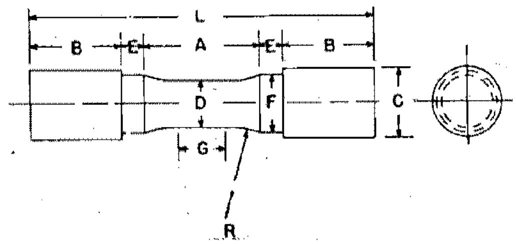
	Specimen 1		Specimen 2		Specimen 3		Specimen 4		Specimen 5	
	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm
G—Gage length	2.000 ± 0.005	50.0 ± 0.10	2.000 ± 0.005	50.0 ± 0.10	2.000 ± 0.005	50.0 ± 0.10	2.000 ± 0.005	50.0 ± 0.10	2.000 ± 0.005	50.0 ± 0.10
D—Diameter (Note 1)	0.500 ± 0.010	12.5 ± 0.25	0.500 ± 0.010	12.5 ± 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.

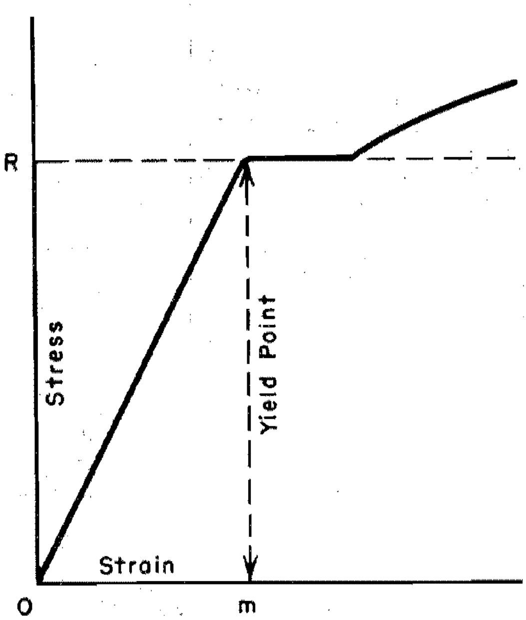


FIG. 8 Stress-Strain Diagram Showing Yield Point Corresponding with Top of Knee.

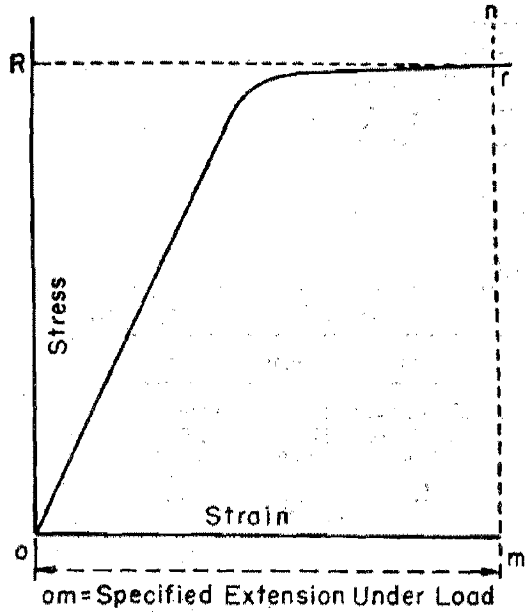


FIG. 9 Stress-Strain Diagram Showing Yield Point or Yield Strength by Extension Under Load Method.

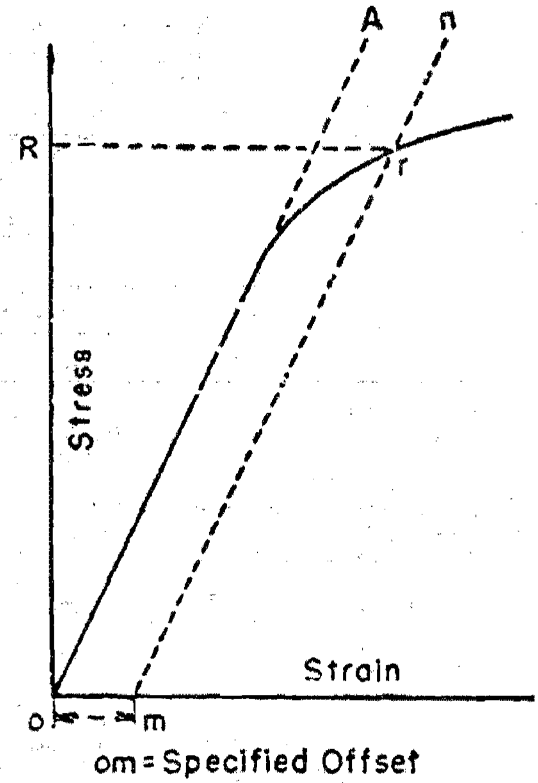
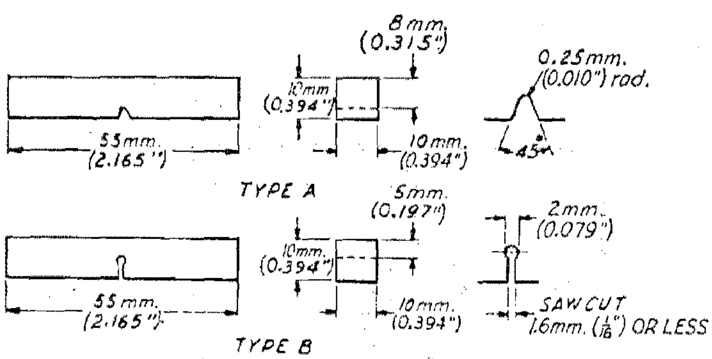


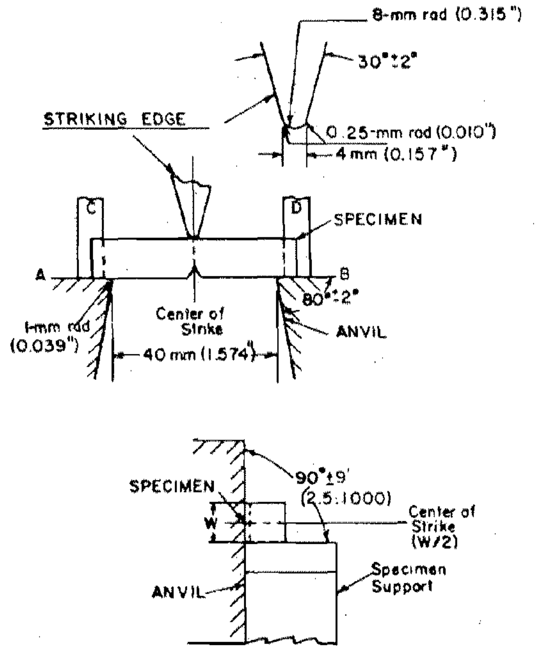
FIG. 10 Stress-Strain Diagram for Determination of Yield Strength by the Offset Method.



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.



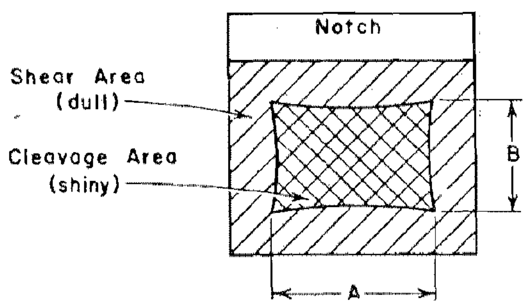
All dimensional tolerances shall be ± 0.05 mm (0.002 in.) unless otherwise specified.

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.

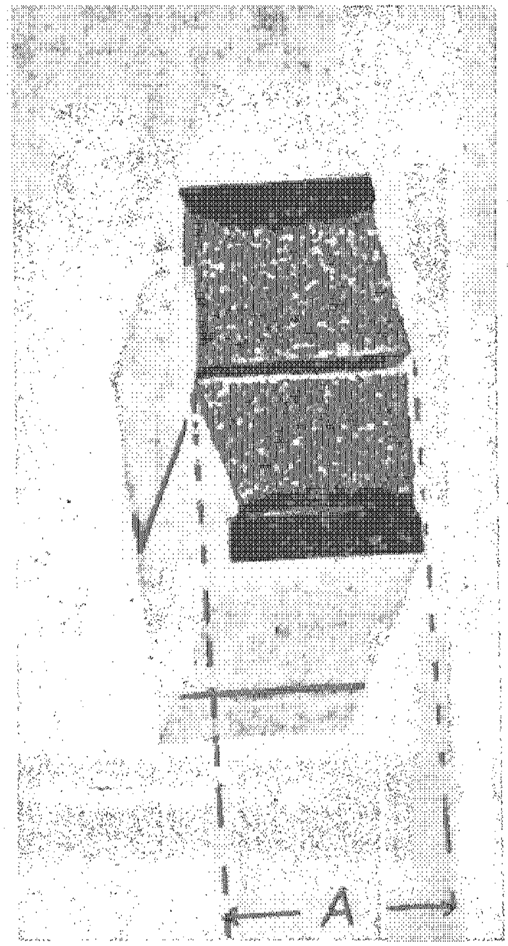


FIG. 13 Halves of Broken Charpy V-Notch Impact Specimen Joined for the Measurement of Lateral Expansion, Dimension *A*.

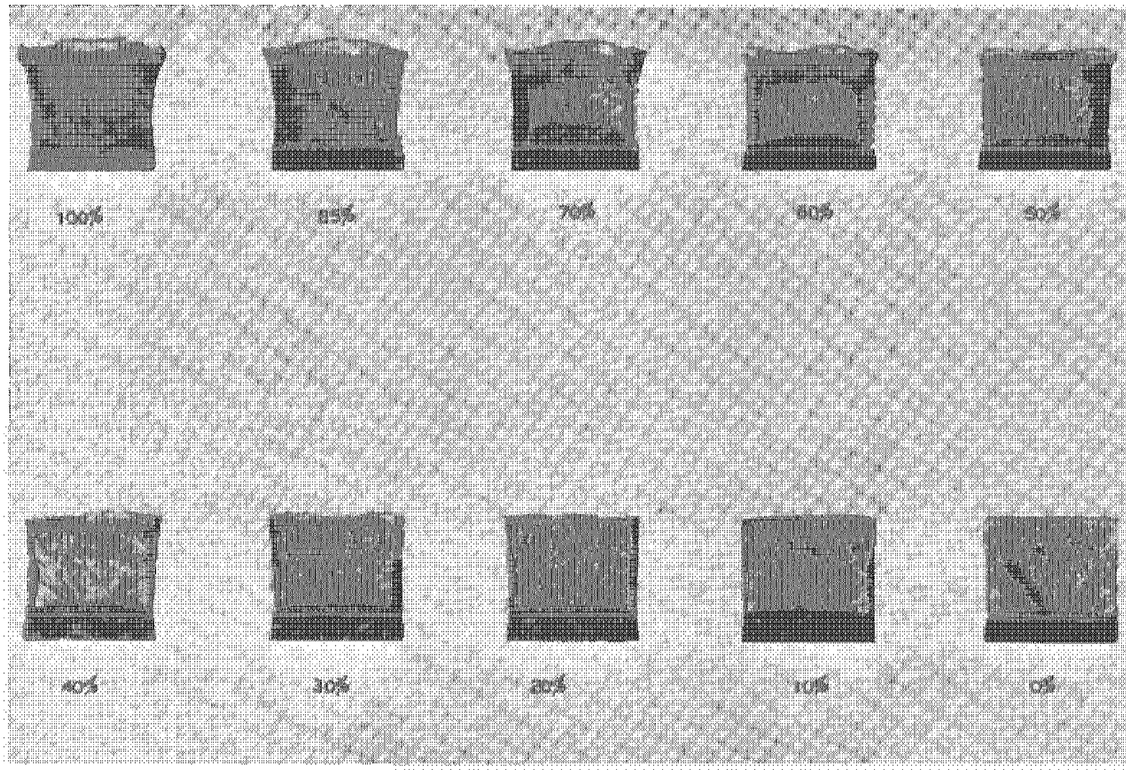


FIG. 15 Fracture Appearance Charts and percent Shear Fracture Comparator.

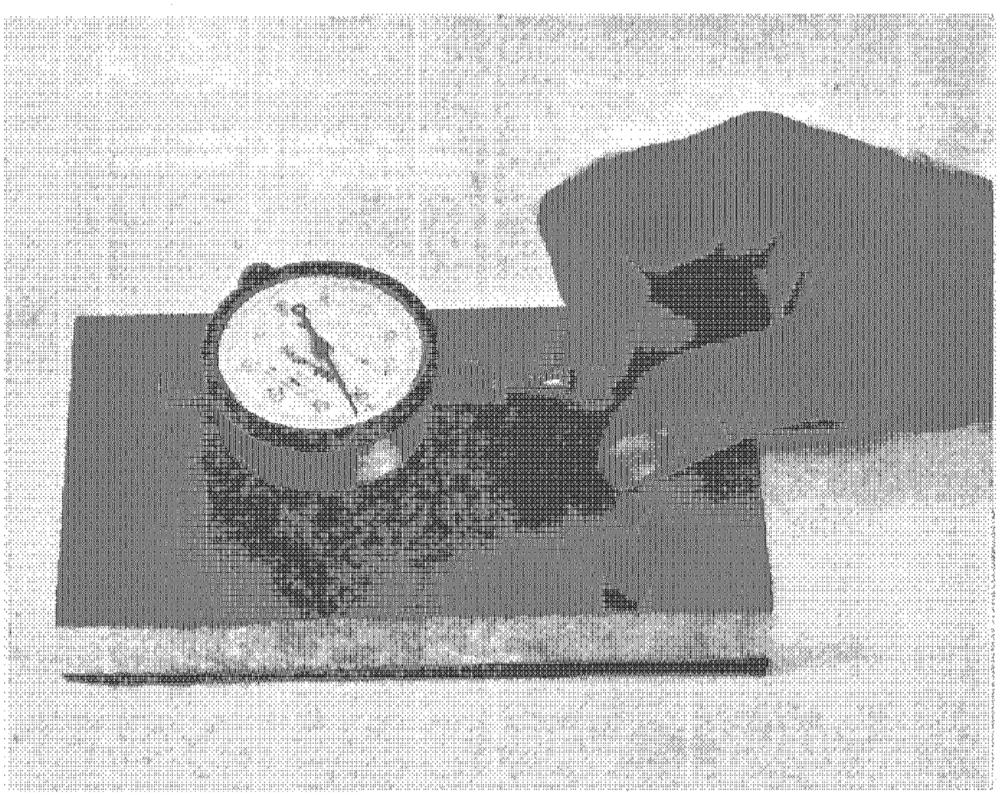
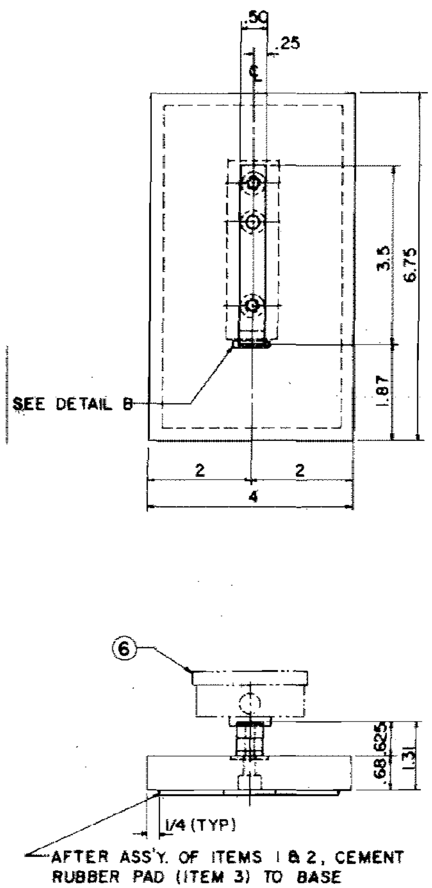
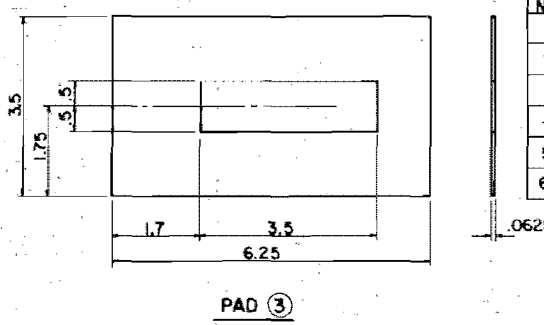
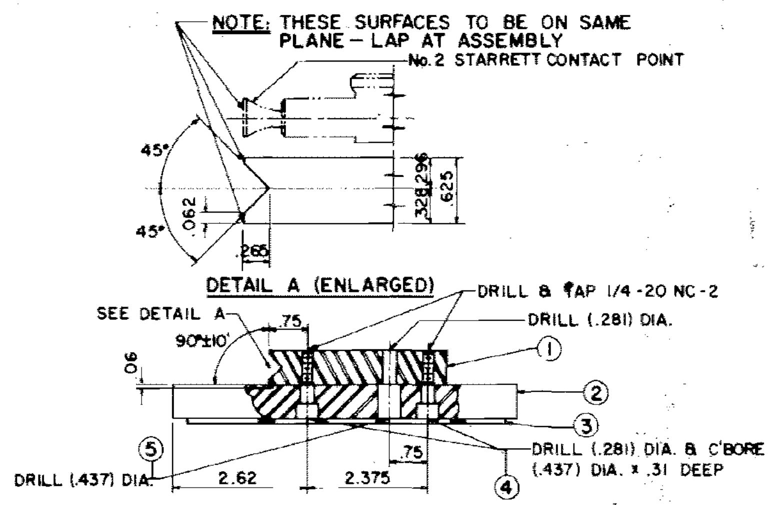


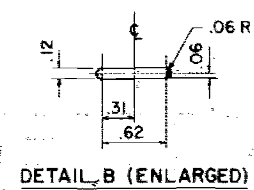
FIG. 16 Lateral Expansion Gage for Charpy Impact Specimens.





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





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.

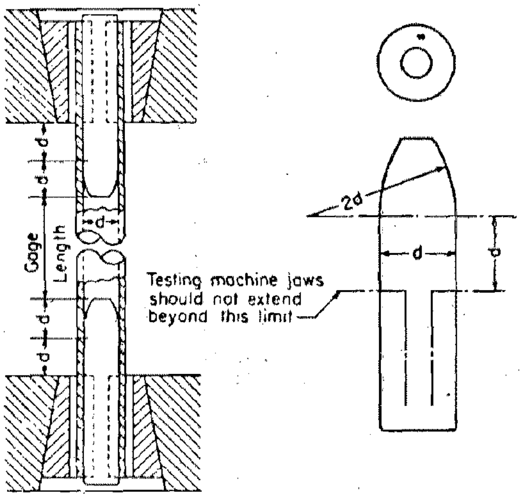


FIG. 18 Metal Plugs for Testing Tubular Specimens, Proper Location of Plugs in Specimen and of Specimen in Heads of Testing Machine.

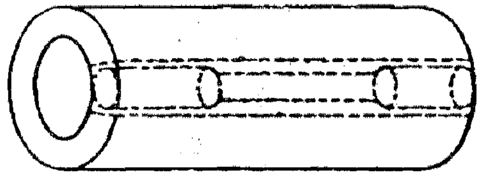
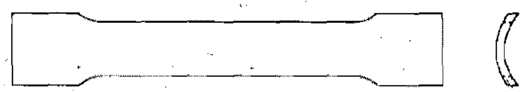
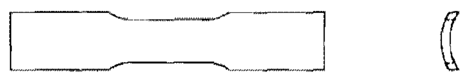


FIG. 19 Location of Longitudinal Tension Test Specimens in Large Diameter Tubing.

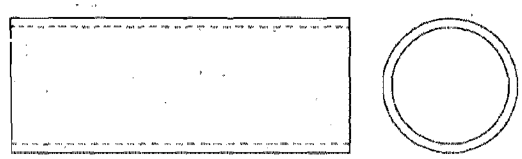
(*a*) Specimen for 8-in. Gage Length Test (Welded Only).



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

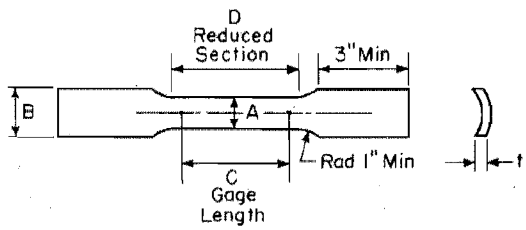


(*c*) Specimen for 2-in. Gage Length Test.



(*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.

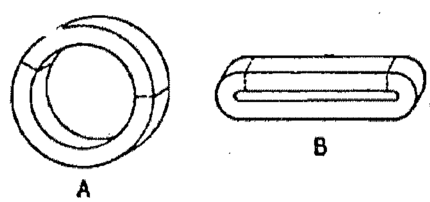


FIG. 22 Location of Transverse Tension Test Specimens in Ring Cut from Tubular Products.

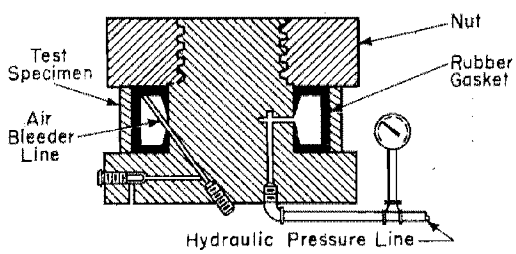
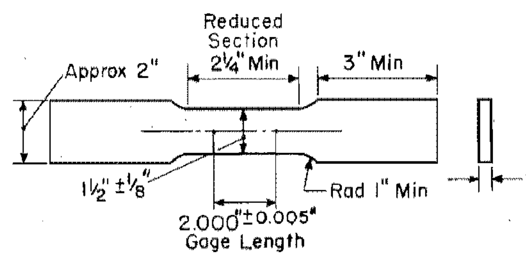


FIG. 24 Testing Machine for Determination of Transverse Yield Strength from Annular Ring Specimens.



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.

PRO_00086158

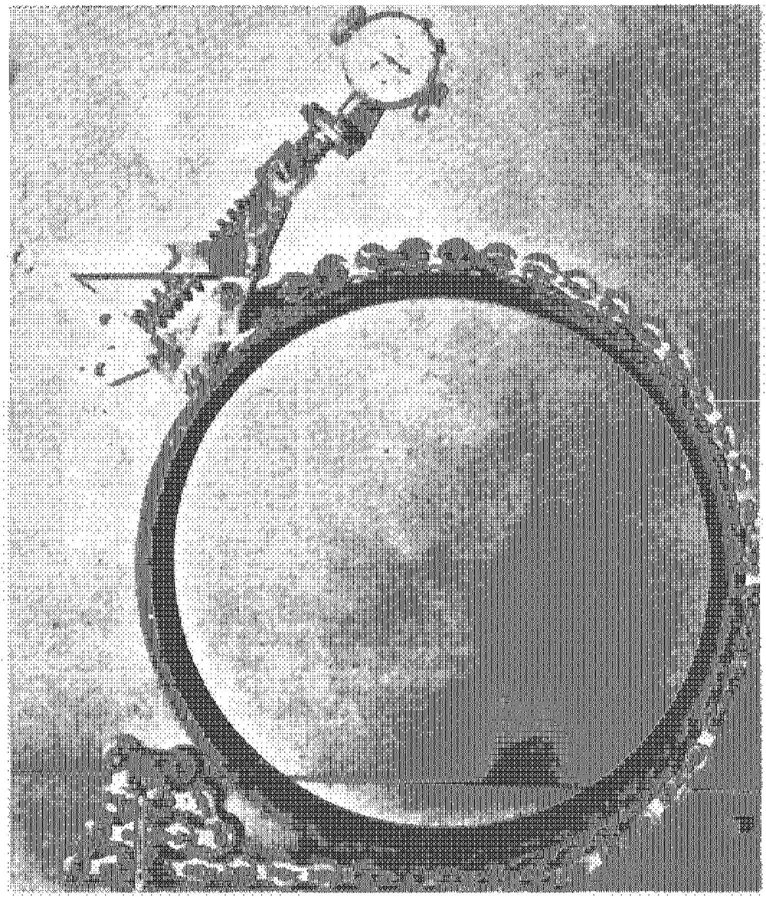


FIG. 25 Roller Chain Type Extensometer, Unclamped.

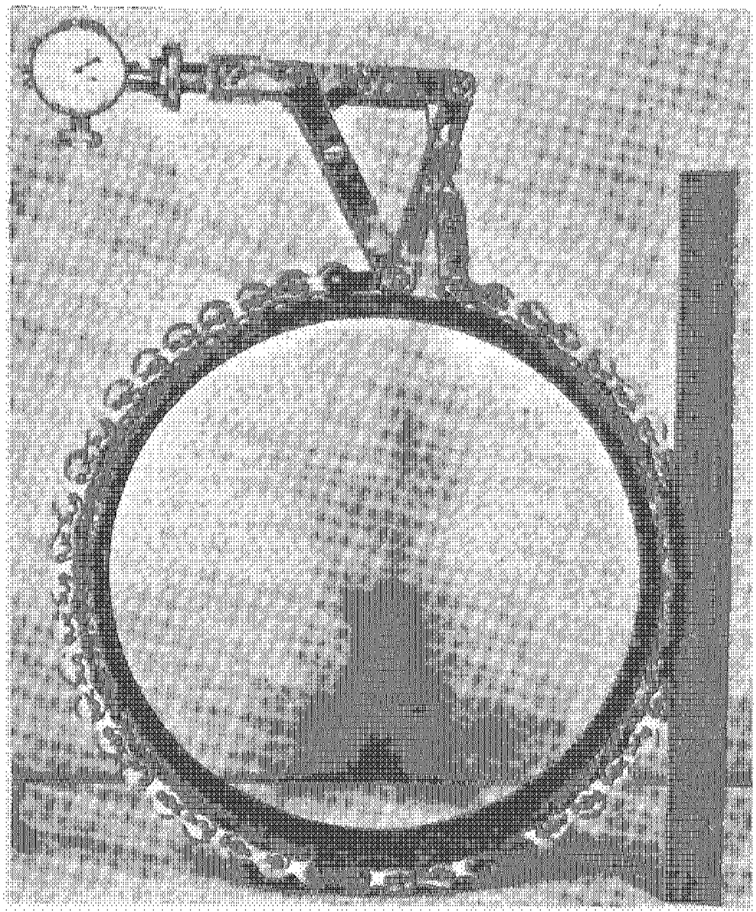


FIG. 26 Roller Chain Type Extensometer, Clamped.

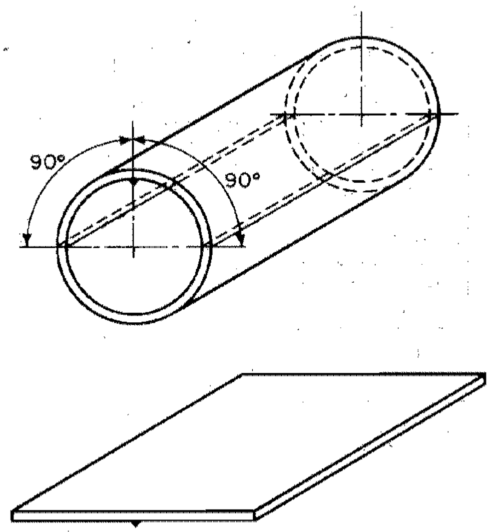


FIG. 27 Reverse Flattening Test.

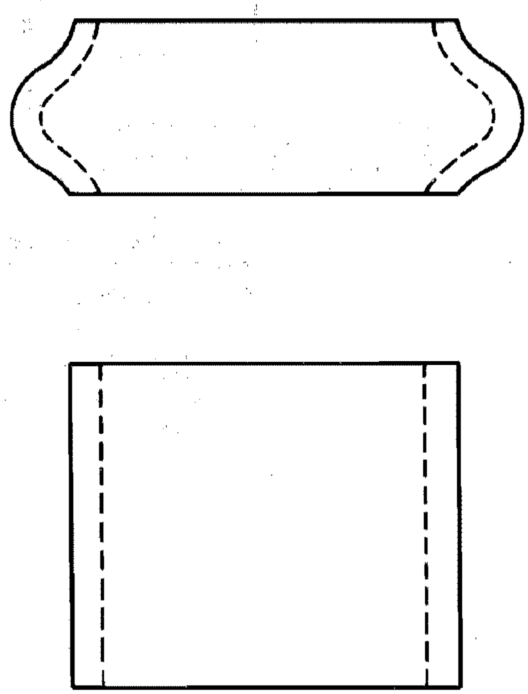
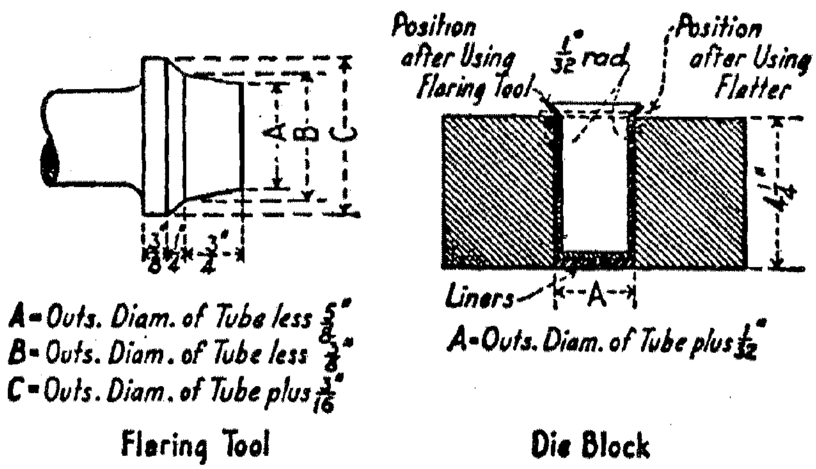


FIG. 28 Crush Test Specimen.



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

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

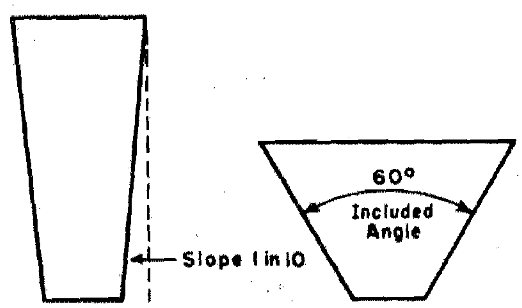
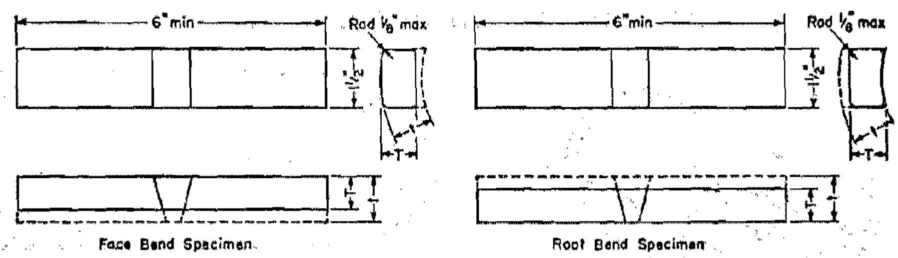


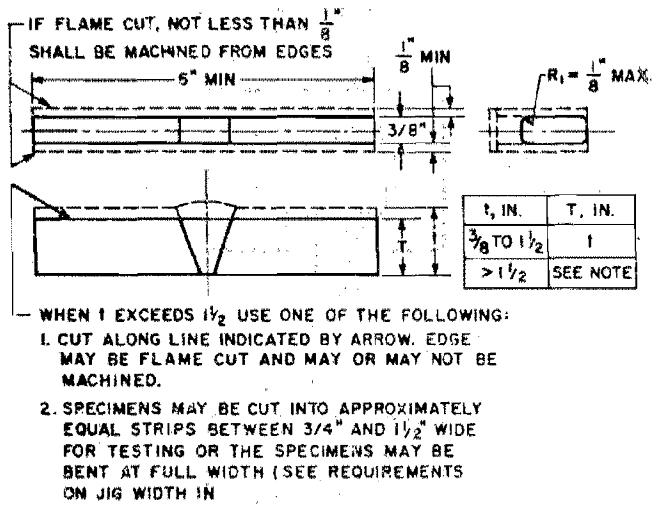
FIG. 30 Tapered Mandrels for Flaring Test.



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

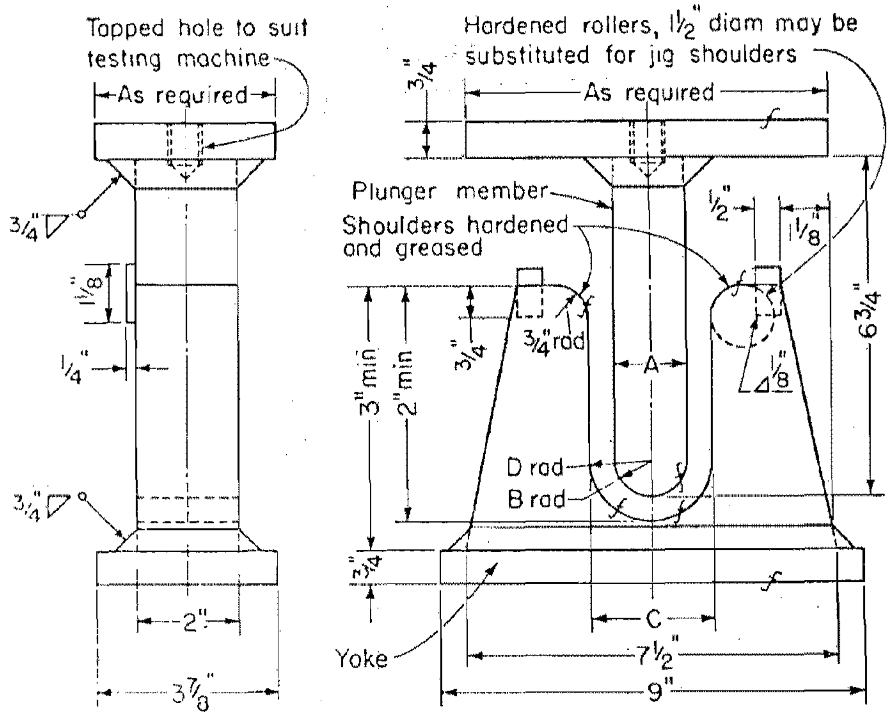
Pipe Wall Thickness (t), in.	Test Specimen Thickness, in.
Up to 3/8, incl	t
Over 3/8	3/8

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.

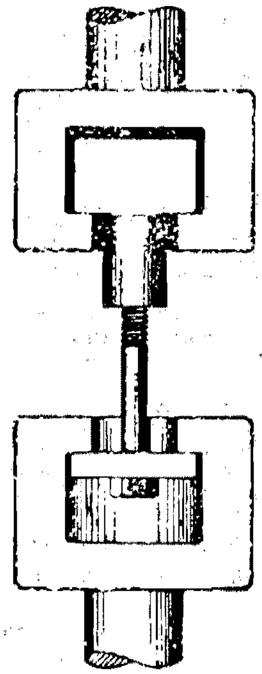
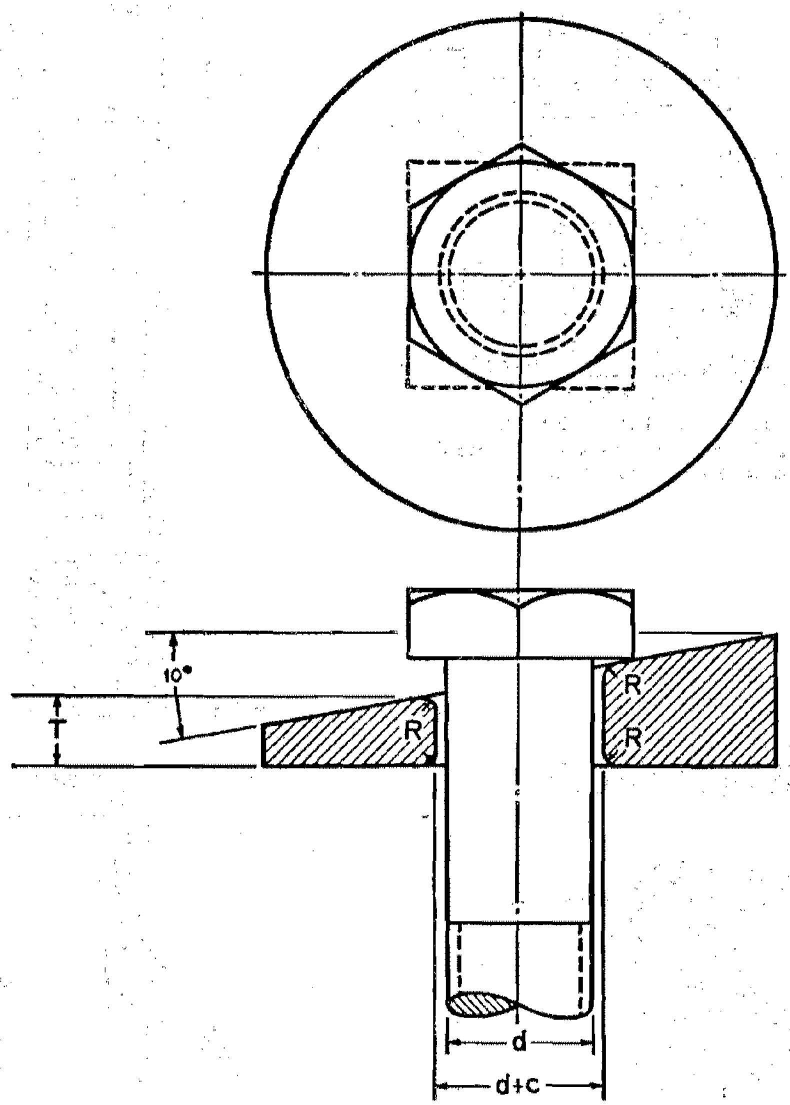
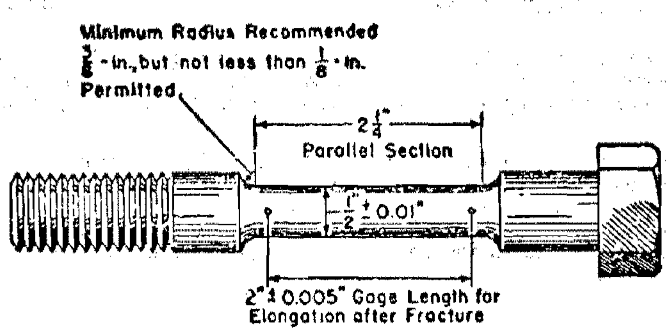


FIG. 33 Tension Testing Full-Size Bolt.



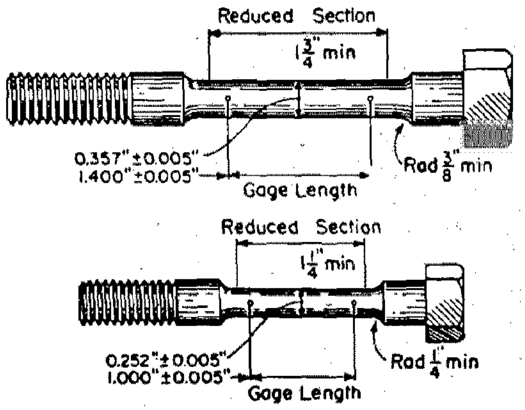
c = Clearance of wedge hole.
d = Diameter of bolt.
R = Radius.
T = Thickness of wedge at short side of hole equal to one-half diameter of bolt.

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.

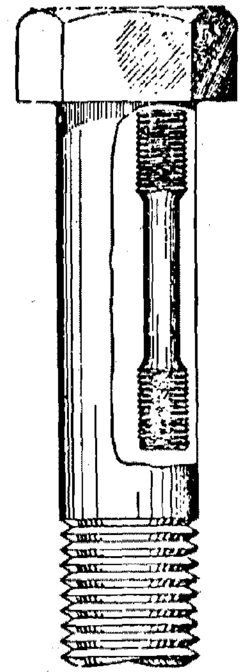


FIG. 37 Location of Standard Round 2-in. Gage Length Tension Test Specimen When Turned from Large Size Bolt.

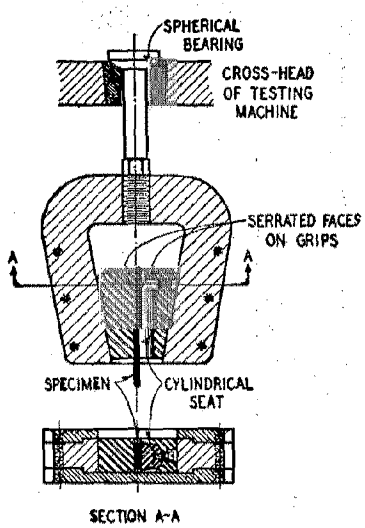


FIG. 38 Wedge-Type Gripping Device.

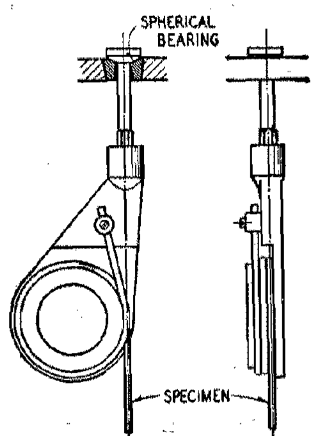


FIG. 39 Snubbing-Type Gripping Device.

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OFFICE OF THE FEDERAL REGISTER
WASHINGTON, D.C.

Standard Specification for

HIGH-STRENGTH LOW-ALLOY STRUCTURAL MANGANESE VANADIUM STEEL[1]

This Standard is issued under the fixed designation A 441; 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.

This specification has been approved for use by agencies of the Department of Defense and for listing in the DoD Index of Specifications and Standards.

1. Scope

1.1 This specification covers high-strength low alloy structural steel shapes, plates, and bars for welded, riveted, or bolted construction but intended primarily for use in welded bridges and buildings where saving in weight or added durability are important. The atmospheric corrosion resistance of this steel is approximately twice that of structural carbon steel. This specification is limited to material up to 8 in. (203 mm) incl. in thickness.

NOTE 1—The values stated in inch-pound units are to be regarded as the standard.

2. General Requirements for Delivery

2.1 Material furnished under this specification shall conform to the applicable requirements of the current edition of Specification A 6 for General Requirements for Rolled Steel Plates, Shapes, Sheet Piling, and Bars for Structural Use.[2]

3. Process

3.1 The steel shall be made by one or more of the following processes: open-hearth, basic-oxygen, or electric-furnace.

4. Chemical Requirements

4.1 The heat analysis shall conform to the requirements prescribed in Table 1.

4.2 The steel shall conform on product analysis to the requirements prescribed in Table 1, subject to the product analysis tolerances in Specification A 6.

5. Tensile Requirements

5.1 The material as represented by the test specimens shall conform to the tensile properties prescribed in Table 2.

5.2 For material under 5⁄16 in. (7.94 mm) in thickness or diameter, as represented by the test specimen, a deduction of 1.25% from the percentage of elongation in 8 in. or 200 mm specified in Table 2 shall be made for each decrease of 1⁄32 in. (0.79 mm) of the specified thickness or diameter below 5⁄16 in.

[1] This specification is under the jurisdiction of ASTM Committee A-1 on Steel, Stainless Steel and Related Alloys, and is the direct responsibility of Subcommittee A01.02 on Structural Steel for Bridges, Buildings, Rolling Stock, and Ships.

Current edition approved Nov. 5, 1979. Published January 1980. Originally published as A 441 – 60 T. Last previous edition A 441 – 77.

[2] *Annual Book of ASTM Standards*, Part 4.

SUPPLEMENTARY REQUIREMENTS

Standardized supplementary requirements for use at the option of the purchaser are listed in Specification A 6. Those which are considered suitable for use with this specification are listed below by title.

S14. Bend Test.

S18. Maximum Tensile Strength.

TABLE 1 Chemical Requirements

	Heat Analysis, %
Carbon, max	0.22
Manganese	0.85–1.25
Phosphorus, max	0.04
Sulfur, max	0.05
Silicon, max	0.40
Copper, min	0.20
Vanadium, min	0.02

TABLE 2 Tensile Requirements

	Plates and Bars[a]				Structural Shapes[b]		
	For Thicknesses ¾ in. (19 mm) and under	For Thicknesses over ¾ to 1½ in. (19 to 38 mm), incl	For Thicknesses over 1½ to 4 in. (38 to 102 mm), incl	For Thicknesses over 4 to 8 in. (102 to 203 mm), incl	Groups 1 and 2	Group 3	Groups 4 and 5
Tensile strength min, psi (MPa)[c]	70 000 (485)	67 000 (460)	63 000 (435)	60 000 (415)	70 000 (485)	67 000 (460)	63 000 (435)
Yield point min, psi (MPa)[c]	50 000 (345)	46 000 (315)	42 000 (290)	40 000 (275)	50 000 (345)	46 000 (315)	42 000 (290)
Elongation in 8 in. or 200 mm, min, %	18[d,e,f]	18[e,f]	18[e,f]	...	18[d]	18	18
Elongation in 2 in. or 50 mm, min, %	...	21[e,f]	21[e,f]	21[e,f]	...	...	21[g]

[a] For plates wider than 24 in. (610 mm), the test specimen is taken in the transverse direction. See 11.2 of Specification A 6.

[b] See Specification A 6, Table A.

[c] When the material is normalized the minimum yield point and minimum tensile strength required shall be reduced 5000 psi (35 MPa).

[d] See 5.2.

[e] Elongation not required to be determined for floor plate.

[f] For plates wider than 24 in. (610 mm), the elongation requirement is reduced two percentage points.

[g] For wide flange shapes over 426 lb/ft elongation in 2 in. or 50 mm of 19% minimum applies.

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Standard Specification for QUENCHED AND TEMPERED STEEL BOLTS AND STUDS[1]

This standard is issued under the fixed designation A 449; 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.

1. Scope

1.1 This specification covers the chemical and mechanical requirements for quenched and tempered, medium carbon steel bolts and studs 3 in. and under in diameter for general applications where high strength is required.

1.2 Suitable nuts are covered in Specification A 563. Unless otherwise specified, the grade and style of nut shall be as follows:

Fastener Size and Surface Finish	Nut Grade and Style[A]
¼ to 1½ in., plain (or with a coating of insufficient thickness to require over-tapped nuts)	B, hex
over 1½ to 3 in., plain (or with a coating of insufficient thickness to require over-tapped nuts)	A, heavy hex
¼ to 3 in., galvanized (or with a coating thickness requiring over-tapped nuts)	C, heavy hex

[A] Nuts of other grades and styles having specified proof load stresses (Specification A 563, Table 3) greater than the specified grade and style of nut are suitable.

NOTE 1—The values stated in inch-pound units are to be regarded as the standard.

2. Applicable Documents

2.1 *ASTM Standards:*

A 153 Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware[2]

A 370 Methods and Definitions for Mechanical Testing of Steel Products.[3]

A 563 Specification for Carbon and Alloy Steel Nuts[4]

2.2 *American National Standards:*[5]

ANSI B1.1 Unified Screw Threads

ANSI B18.2.1 Square and Hex Bolts and Screws

3. Material and Manufacture

3.1 Steel for bolts and studs shall be made by the open-hearth, basic-oxygen, or electric-furnace process.

3.2 The bolts and studs shall be heat treated by quenching in a liquid medium from above the transformation temperature and then tempering by reheating to a temperature of not less than 800°F (427°C).

3.3 Threads of bolts and studs shall be rolled, cut, or ground.

3.4 When specified, galvanized fasteners shall be hot-dip galvanized in accordance with the requirements of Class C of Specification A 153. When specified by the purchaser to be mechanically galvanized, fasteners covered by this specification shall be mechanically zinc-coated, and the coating shall conform to requirements for Class 50 of Specification B 454, or to the coating thickness, adherence, and quality requirements for Class C of Specification A 153.

NOTE 2—When the intended application requires that assembled tension exceeds 50 % of minimum bolt or stud proof load, an anti-galling lubricant may be needed. Application of such a lubricant to nuts and a test of the lubricant efficiency are provided in Supplementary Requirement S1 of Specification A 563 and should be specified when required.

4. Chemical Requirements

4.1 The bolts and studs shall conform to requirements as to the chemical composition specified in Table 1.

4.2 Product analyses may be made by the

[1] This specification is under the jurisdiction of ASTM Committee F-16 on Fasteners, and is the direct responsibility of Subcommittee F 16.02 on Steel Bolting.

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[2] *Annual Book of ASTM Standards,* Part 3.

[3] *Annual Book of ASTM Standards,* Parts 1 to 5 and 10.

[4] *Annual Book of ASTM Standards,* Parts 1 and 4.

[5] May be obtained from American National Standards Institute, Inc., 1430 Broadway, New York, NY 10018.

purchaser from finished material representing each lot. The chemical composition thus determined shall conform to the requirements prescribed for product analysis in Table 1.

4.3 Application of heats of steel to which bismuth, selenium, tellurium, or lead has been intentionally added shall not be permitted.

5. Mechanical Requirements

5.1 Bolts and studs shall not exceed the maximum hardness specified in Table 2. Bolts less than three diameters in length and studs less than four diameters in length shall have hardness values not less than the minimum nor more than the maximum hardness limits required in Table 2, as hardness is the only requirement.

5.2 Bolts and studs 1¼ in. in diameter or less, other than those excepted in 4.1, shall be tested full size and shall conform to the tensile strength and either the proof load or yield strength requirements specified in Tables 3 and 4.

5.3 Bolts and studs larger than 1¼ in. in diameter as above, other than those excepted in 5.1, shall preferably be tested full size and when so tested, shall conform to the tensile strength and either the proof load or yield strength requirements specified in Tables 3 or 4 respectively. When equipment of sufficient capacity for full-size testing is not available, or when the length of the bolt or stud makes full-size testing impractical, machined specimens shall be tested and shall conform to the requirements of Table 5. In the event that bolts are tested by both full size and by the machined test specimen methods, the full-size test shall govern if a controversy between the two methods exists.

5.4 For bolts and studs on which both hardness and tension tests are performed, acceptance based on tensile requirements shall take precedence over low readings of hardness tests.

6. Dimensions

6.1 Unless otherwise specified, the bolts shall be finished hexagon head with dimensions conforming to the latest issue of ANSI B18.2.1.

6.2 Studs shall have dimensions conforming to those specified by the purchaser.

6.3 Unless otherwise specified, threads shall be Coarse Thread Series as specified in the latest issue of ANSI B1.1, and shall have Class 2A tolerances.

6.4 Unless otherwise specified, bolts to be used with nuts or tapped holes that have been tapped oversize, in accordance with Specification A 563, shall have Class 2A threads before hot dip or mechanical galvanizing. After galvanizing, the maximum limit of pitch and major diameter may exceed the Class 2A limit by the following amount:

Diameter, in.	Oversize Limit, in. (mm)[A]
Up to 7/16, incl	0.016(0.41)
Over 7/16 to 1, incl	0.021(0.53)
Over 1	0.031(0.79)

[A] These values are the same as the minimum overtapping required for galvanized nuts in Specification A 563.

6.5 The gaging limit for bolts shall be verified during manufacture or use by assembly of a nut tapped as nearly as practical to the amount oversize shown above. In case of dispute, a calibrated thread ring gage of that same size (Class X tolerance, gage tolerance plus) is to be used. Assembly of the gage, or the nut described above, must be possible with hand effort following application of light machine oil to prevent galling and damage to the gage. These inspections, when performed to resolve disputes, are to be performed at the frequency and quality described in Table 6.

7. Test Methods

7.1 Bolts and studs shall be tested in accordance with Supplement III of Methods A 370.

7.2 The wedge test shall be applicable only to square and hexagon head bolts.

7.3 Studs shall be tested by the Axial Tension Method as described in S11.1.3.1, Supplement III of Methods A 370.

8. Number of Tests and Retests

8.1 The requirements of this specification shall be met in continuous mass production for stock, and the manufacturer shall make sample inspections to ensure that the product conforms to the specified requirements. Additional tests of individual shipments of material are not ordinarily contemplated. Individual heats of steel are not identified in the finished product.

8.2 When specified in the order, the manufacturer shall furnish a test report certified to be the last completed set of mechanical tests for each stock size in each shipment.

8.3 When testing on a lot basis is specified on the purchase order, a lot, for purposes of selecting test samples, shall consist of all material of one type, that is, bolts or studs having the same nominal diameter and length offered for inspection at one time. From each lot, the number of tests for each specified property shall be as follows:

Number of Pieces in Lot	Number of Samples
800 and less	1
Over 800 to 8 000, incl	2
Over 8 000 to 22 000, incl	3
Over 22 000	5

8.4 Should any sample fail to meet the requirements of a specified test, double the original number of samples from the same lot shall be retested for the requirement(s) in which it failed. All the additional samples shall conform to the specification or the lot shall be rejected.

8.5 If any test specimen shows defective machining, it may be discarded and another specimen substituted.

9. Workmanship

9.1 The bolts and studs shall be commercially smooth and free from burrs, laps, seams, cracks, and other injurious material or manufacturing defects which would make them unsuitable for the intended application.

10. Marking

10.1 Bolt heads shall be marked with 3 radial lines 120 deg apart and with a symbol identifying the manufacturer. Markings may be raised or depressed at the option of the manufacturer.

11. Inspection

11.1 If the inspection described in 8.2 is required by the purchaser, it shall be specified in the inquiry and contract or order.

11.2 The inspector representing the purchaser shall have free entry, at all times while work on the contract of the purchaser is being performed, to all parts of manufacturer's works that concern the manufacture and testing of the material ordered. The manufacturer shall afford the inspector all reasonable facilities, without charge, to satisfy him that the material is being furnished in accordance with this specification. All tests (except product analysis) and inspection shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

12. Rejection

12.1 Rejections based on requirements specified herein shall be reported to the manufacturer within 30 days after receipt of material by the purchaser.

TABLE 1 Chemical Requirements

	Composition, %	
	Heat Analysis	Product Analysis
Carbon	0.28–0.55	0.25–0.58
Manganese, min	0.60	0.57
Phosphorus, max	0.040	0.048
Sulfur, max	0.050	0.058

TABLE 2 Hardness Requirements

	Hardness	
Bolt or Stud Diameter, in.	Brinell Hardness Number	Rockwell C
¼ to 1, incl	255 to 321	25 to 34
Over 1 to 1½, incl	223 to 285	19 to 30
Over 1½ to 3, incl	183 to 235	...

TABLE 3 Tensile Requirements for Coarse-Thread Full-Size Bolts and Studs

Bolt or Stud Diameter, in.	Threads per inch[A]	Stress Area, in.^{2} [B]	Tensile Load, min, lbf[C]	Proof Load, Length Measurement Method, lbf[C]	Alternative Proof Load, Yield Strength Method (0.2 % Off-set), lbf[C]
Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
¼	20	0.0318	3 800	2 700	2 900
5/16	18	0.0524	6 300	4 450	4 800
⅜	16	0.0775	9 300	6 600	7 100
7/16	14	0.1063	12 750	9 050	9 800
½	13	0.1419	17 050	12 050	13 050
9/16	12	0.182	21 850	15 450	16 750
⅝	11	0.226	27 100	19 200	20 800
¾	10	0.334	40 100	28 400	30 700
⅞	9	0.462	55 450	39 250	42 500
1	8	0.606	72 700	51 500	55 750
1⅛	7	0.763	80 100	56 450	61 800
1¼	7	0.969	101 700	71 700	78 500
1⅜	6	1.155	121 300	85 450	93 550
1½	6	1.405	147 500	104 000	113 800
1¾	5	1.90	171 000	104 500	110 200
2	4½	2.50	225 000	137 500	145 000
2¼	4½	3.25	292 500	178 750	188 500
2½	4	4.00	360 000	220 000	232 000
2¾	4	4.93	443 700	271 150	286 000
3	4	5.97	537 300	328 350	346 200

[A] For 8 threads per inch in sizes 1⅛ to 1½ in., incl, stresses of 105,000 psi (725 MPa), 74,000 psi (510 MPa), and 81,000 psi (560 MPa) shall be used for calculating the values in columns 4, 5, and 6 respectively.

[B] Stress area calculated from the formula:

$$A_s = 0.7854\,[D - 0.9743/n)]^2$$

where:

A_s = stress area,
D = nominal diameter, and
n = threads per inch.

[C] Values tabulated are based on the following:

Bolt Size, in.	Column 4, psi (MPa)	Column 5, psi (MPa)	Column 6, psi (MPa)
¼ to 1, incl	120 000 (825)	85 000 (585)	92 000 (635)
1⅛ to 1½, incl	105 000 (725)	74 000 (510)	81 000 (560)
1¾ to 3, incl	90 000 (620)	55 000 (380)	58 000 (400)

TABLE 4 Tensile Requirements for Fine-Thread Full-Size Bolts and Studs

Bolt or Stud Diameter, in.	Threads per inch	Stress Area, in.[2A]	Tensile Load, min, lbf[B]	Proof Load, Length Measurement Method, lbf[B]	Alternative Proof Load, Yield Strength Method (0.2 % Offset), min, lbf[B]
Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
¼	28	0.0364	4 350	3 100	3 500
5⁄16	24	0.0580	6 950	4 950	5 350
⅜	24	0.0878	10 550	7 450	8 100
7⁄16	20	0.1187	14 500	10 100	10 900
½	20	0.1599	19 200	13 600	14 700
9⁄16	18	0.203	24 350	17 250	18 700
⅝	18	0.256	30 700	21 750	23 500
¾	16	0.373	44 750	31 700	34 300
⅞	14	0.509	61 100	43 250	46 800
1	12	0.663	79 550	56 350	61 000
1⅛	12	0.856	89 900	63 350	69 350
1¼	12	1.073	112 650	79 400	86 900
1⅜	12	1.315	138 100	97 300	106 500
1½	12	1.581	166 000	117 000	128 000

[A] See footnote[B] below Table 3.
[B] See footnote[C] below Table 3.

TABLE 5 Tensile Requirements for Specimens Machined from Bolts and Studs

Bolt or Stud Diameter, in.	Tensile Strength, min, psi (MPa)	Yield Strength, min, psi (MPa)	Elongation in 4 *D* min, %	Reduction of Area, min, %
¼ to 1, incl	120 000 (825)	92 000 (635)	14	35
Over 1 to 1½, incl	105 000 (725)	81 000 (560)	14	35
Over 1½ to 3, incl	90 000 (620)	58 000 (400)	14	35

TABLE 6 Sample Sizes and Acceptance Numbers for Inspection of Hot Dip or Mechanically Galvanized Threads

Lot Size	Sample Size[A, B]	Acceptance Number[A]
2 to 90	13	1
91 to 150	20	2
151 to 280	32	3
281 to 500	50	5
501 to 1 200	80	7
1 201 to 3 200	125	10
3 201 to 10 000	200	14
10 001 and over	315	21

[A] Sample sizes of acceptance numbers are extracted from "Single Sampling Plan for Normal Inspection" Table IIA, MIL-STD-105D.
[B] Inspect all bolts in the lot if the lot size is less than the sample size.

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By the Authority Vested By Part 5 of the United States Code § 552(a) and Part 1 of the Code of Regulations § 51 the attached document has been duly INCORPORATED BY REFERENCE and shall be considered legally binding upon all citizens and residents of the United States of America. *HEED THIS NOTICE*: Criminal penalties may apply for noncompliance.

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Standard Specification for Zinc-Coated Steel Wire Strand[1]

This standard is issued under the fixed designation A 475; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This specification has been approved for use by agencies of the Department of Defense and for listing in the DoD Index of Specifications and Standards.

$^{\epsilon 1}$ NOTE—Section 2 was added editorially and subsequent sections were renumbered in April 1984.

1. Scope

1.1 This specification covers five grades of zinc-coated, steel wire strand, composed of a number of round, steel wires, with four weights of zinc coatings, suitable for use as guys, messengers, span wires, and for similar purposes.

1.2 The five grades covered are as follows:

1.2.1 Utilities,

1.2.2 Common,

1.2.3 Siemens-Martin,

1.2.4 High-Strength, and

1.2.5 Extra High-Strength.

1.2.6 Minimum breaking strengths of strand for each grade are specified in Table 1.

1.3 The four weights of zinc coatings are: Type 1 and Classes A, B, and C. Minimum weights of zinc coatings are specified in Table 4.

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

2. Referenced Documents

2.1 *ASTM Standards:*

A 90 Test Method for Weight of Coating on Zinc-Coated (Galvanized) Iron or Steel Articles[2]

B 6 Specification for Zinc (Slab Zinc)[3]

3. Description of Strand

3.1 The designation of the finished strand shall be expressed as the nominal diameter of the strand, the number of the wires in the strand, and the minimum breaking strength of the strand as prescribed in Table 1, and the type or class of coating as prescribed in Table 4.

4. Ordering Information

4.1 Orders for material under this specification shall include the following information:

4.1.1 Quantity of strand in feet,

4.1.2 Nominal strand diameter, number of wires, grade, and minimum breaking strength of strand (Section 8 and Table 1),

4.1.3 Weight (type and class) of zinc-coating (Section 12 and Table 4), and

4.1.4 Length of strand in coils or on reels (Section 17).

5. Material

5.1 The base metal shall be steel made by the open-hearth, basic-oxygen, or electric-furnace process and of such quality and purity that, when drawn to the size of wire specified and coated with zinc, the finished strand and the individual wires shall be of uniform quality and have the properties and characteristics as prescribed in this specification.

5.2 The slab zinc, when used for the coating, shall be any grade of zinc conforming to Specification B 6.

6. Stranding

6.1 Unless otherwise specified, strand shall have a left lay. A left lay is defined as a counter-clockwise twist away from the observer. All wires shall be stranded with uniform tension. Stranding shall be sufficiently close to ensure no appreciable reduction in diameter when stressed to 10 % of the specified strength.

6.2 The 3-wire strand shall consist of three wires concentrically twisted with a uniform pitch of not less than 14 nor more than 20× the specified nominal diameter of the strand.

6.3 The 7-wire strand shall consist of a center wire with a 6-wire layer concentrically twisted over it with a uniform pitch of not more than 16× the specified nominal diameter of the strand.

6.4 The 19-wire strand shall consist of a center wire with a 6-wire layer concentrically twisted over it, having a right lay and a uniform pitch of not more than 16× the nominal diameter of this 7-wire core. The nominal diameter of this 7-wire core shall be considered to be 3× the nominal diameter of the wires. A 12-wire outer layer, having a left lay shall be concentrically twisted over the 7-wire core and shall have a uniform pitch of not more than 16× the specified nominal diameter of the strand.

6.5 The 37-wire strand shall consist of a center wire with a 6-wire layer concentrically twisted over it, having a left lay and a uniform pitch of not more than 16× the nominal diameter of this 7-wire inner core. The nominal diameter of this 7-wire inner core shall be considered to be 3× the nominal diameter of the wire. An intermediate layer of 12

[1] This specification is under the jurisdiction of ASTM Committee A-5 on Metallic Coated Iron and Steel Products and is the direct responsibility of Subcommittee A05.12 on Wire Specifications.

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[2] *Annual Book of ASTM Standards*, Vol 01.06.

[3] *Annual Book of ASTM Standards*, Vols 02.03 and 02.04.

wires having a right lay shall be concentrically twisted over this 7-wire core and shall have a uniform pitch of not more than 16× the nominal diameter of this 19-wire core. The nominal diameter of this 19-wire core shall be considered as 5× the nominal diameter of the wires. An 18-wire outer layer, having a left lay shall be concentrically twisted over the 19-wire core and shall have a uniform pitch of not more than 16× the specified nominal diameter of the strand.

6.6 All wires in the strand shall lie naturally in their true positions in the completed strand and, when the strand is cut, the ends shall remain in position or be readily replaced by hand and then remain in position. This may be accomplished by any means or process, such as preforming, post forming or form setting.

7. Joints and Splices

7.1 Electric-welded butt joints made prior to the start of cold drawing of the wire are permitted.

7.2 In 3-wire strand, there shall be no joints made in the individual finished wire. In 7-wire strand, joints made in individual finished wires shall be acceptable provided there is not more than one joint in any 150-ft (45.7-m) section of the completed strand and the location of each joint is marked on the strand with paint or some other distinguishing mark. Factory joints made in the individual finished wires of 19 and 37-wire strand shall be kept well spaced and at a minimum in number.

7.3 Joints in the wires composing the strand shall be either the brazed-lap type or electric-butt-welded type. When the brazed type of joint is used, the length of the lap shall be not less than 3× the diameter of the wire and the overlapping faces shall be smooth, clean, properly fluxed, and completely covered by the brazing metal. When the electric-welded type of joint is used, care shall be taken to prevent injury to the wire during electric-butt welding. All joints shall be well made and shall be coated with zinc after completion so that the joints shall have protection from corrosion equivalent to that of the zinc-coated wire itself.

7.4 There shall be no strand joints or strand splices in any length of the completed strand unless specifically permitted by the purchaser.

8. Breaking Strength and Weight

8.1 The approximate weight per 1000 ft or 305 m, of strand, and the minimum breaking strength of the finished strand shall be as specified in Table 1.

8.2 A test in which the breaking strength is below the minimum specified and which may have been caused by the slipping of the specimen in the jaws of the testing machine, by breaking within the jaws or within 1 in. (25.4 mm) of the jaws, or by the improper socketing of a specimen shall be disregarded and another sample from the same coil or reel shall be tested. Tests shall be made on lengths of strand that do not contain wire joints or splices.

9. Elongation

9.1 The elongation of the strand in 24 in. (610 mm) shall be not less than that specified in Table 2.

9.2 The elongation shall be determined as the percent increase in separation between the jaws of the testing machine from the position after application of the initial load to the position at the initial failure in the test specimen. The separation of the jaws of the testing machine shall be approximately 2 ft when under an initial load equal to 10 % of the required minimum breaking strength of the strand. The elongation values shall be recorded only for specimens which break over 1 in. from the jaws of the testing machine. Additional samples shall be taken from the same coil or reel when the previous tests are to be disregarded.

9.3 Elongation tests shall be made on lengths of strand which do not contain wire joints of splices.

10. Permissible Variations in Size

10.1 The diameter of the zinc-coated wire forming the strand specified in Table 1 shall be within the limits prescribed in Table 3.

11. Sampling

11.1 Sampling for determination of compliance to this specification shall be performed on each lot of material. A lot shall consist of all the strand of one size and one grade in each shipment. The number of samples to be taken shall be as follows:

	Number of Samples
5000 ft (1524 m) or less	1
Over 5000 to 30 000 ft (1524 to 9144 m)	2
Over 30 000 to 150 000 ft (9144 to 45 720 m)	3
Over 150 000 ft (45 720 m)	4

11.2 Each sample taken shall be subjected to all tests prescribed in Sections 6, 8, and 9.

11.3 In addition to the strand testing in 11.2, the individual wires shall be tested. The number of individual wires to be selected from each sample of strand and tested to determine compliance with Sections 10, 12, 14, and 15 shhll be as follows:

3-wire strand—3 wires
7-wire strand—4 wires
19-wire strand—3 wires from each layer (total of 6 wires)
37-wire strand—3 wires from each layer (total of 9 wires)

NOTE 1—Individual wire samples selected for compliance to Section 10 shall be discarded if any distortion of the wire occurred during the stranding operation.

11.4 Instead of testing the wires from the completed strand in accordance with 11.3, the producer may elect to establish compliance with Sections 10, 12, 14, and 15 of this specification by tests made on the wires prior to stranding, unless otherwise stipulated by the purchaser. However, if the producer makes this election, the purchaser still reserves the right to test wires from the completed strand for compliance.

12. Weight of Coating

12.1 The weight of zinc-coating, in ounces per square foot or grams per square metre of uncoated wire surface, shall not be less than that specified in Table 4.

13. Tests of Coating

13.1 The weight of the zinc-coating shall be determined by a stripping test in accordance with Test Method A 90.

TABLE 1 Physical Properties of Zinc-Coated Steel Wire Strand

NOTE—The numbers in **boldface type** indicate sizes and grades most commonly used and readily available.

Nominal Diameter of Strand, in. (mm)	Number of Wires in Strand	Nominal Diameter of Coated Wires in Strand, in. (mm)	Approximate Weight of Strand, lb/1000 ft (kg/304.8 m)	Minimum Breaking Strength of Strand, lbf (kN): Utilities Grade[A]	Common Grade	Siemens-Martin Grade	High-Strength Grade	Extra High-Strength Grade
1/8 (3.18)	7	0.041 (1.04)	32 (15)	. . .	**540 (2.402)**	910 (4.048)	1 330 (5.916)	1 830 (8.140)
5/32 (3.97)	7	0.052 (1.32)	51 (23)	. . .	**870 (3.870)**	1 470 (6.539)	2 140 (9.519)	2 940 (13.078)
3/16 (4.76)	7	0.062 (1.57)	73 (33)	. . .	**1 150 (5.115)**	1 900 (8.452)	2 850 (12.677)	3 990 (17.748)
3/16 (4.76)	7	0.065 (1.65)	80 (36)	**2 400 (10.676)** (1)[B]	. . .	. . .	. . .	. . .
7/32 (5.56)	3	0.104 (2.64)	88 (40)	. . .	1 400 (6.228)	2 340 (10.409)	3 500 (15.569)	4 900 (21.796)
7/32 (5.56)	7	0.072 (1.83)	98 (44)	. . .	1 540 (6.850)	2 560 (11.387)	3 850 (17.126)	5 400 (24.020)
1/4 (6.35)	3	0.120 (3.05)	117 (53)	**3 150 (14.012)** (2)[B]	1 860 (8.274)	3 040 (13.523)	4 730 (21.040)	6 740 (29.981)
1/4 (6.35)	3	0.120 (3.05)	117 (53)	**4 500 (20.017)** (3)[B]	. . .	. . .	. . .	. . .
1/4 (6.35)	7	0.080 (2.03)	121 (55)	. . .	**1 900 (8.452)**	**3 150 (14.012)**	4 750 (21.129)	6 650 (29.581)
9/32 (7.14)	3	0.130 (3.30)	137 (62)	. . .	2 080 (9.252)	3 380 (15.035)	5 260 (23.398)	7 500 (33.362)
9/32 (7.14)	7	0.093 (2.36)	164 (74)	**4 600 (20.462)** (1)[B]	2 570 (11.432)	4 250 (18.905)	6 400 (28.469)	8 950 (39.812)
5/16 (7.94)	3	0.145 (3.68)	171 (78)	**6 500 (28.913)** (3)[B]	2 490 (11.076)	4 090 (18.193)	6 350 (28.246)	9 100 (40.479)
5/16 (7.94)	7	0.104 (2.64)	205 (93)	. . .	**3 200 (14.234)**	5 350 (23.798)	**8 000 (35.586)**	11 200 (49.820)
5/16 (7.94)	7	0.109 (2.77)	225 (102)	**6 000 (26.689)** (1)[B]	. . .	. . .	. . .	. . .
3/8 (9.52)	3	0.165 (4.19)	220 (100)	**8 500 (37.810)** (3)[B]	3 330 (14.813)	5 560 (24.732)	8 360 (37.187)	11 800 (52.489)
3/8 (9.52)	7	0.120 (3.05)	273 (124)	**11 500 (51.155)** (4)[B]	**4 250 (18.905)**	**6 950 (30.915)**	10 800 (48.040)	15 400 (68.503)
7/16 (11.11)	7	0.145 (3.68)	399 (181)	**18 000 (80.068)** (4)[B]	**5 700 (25.355)**	**9 350 (41.591)**	**14 500 (64.499)**	20 800 (92.523)
1/2 (12.70)	7	0.165 (4.19)	517 (234)	**25 000 (111.206)** (4)[B]	**7 400 (32.917)**	**12 100 (53.823)**	**18 800 (83.627)**	26 900 (119.657)
1/2 (12.70)	19	0.100 (2.54)	504 (229)	. . .	7 620 (33.895)	12 700 (56.492)	19 100 (84.961)	26 700 (118.768)
9/16 (14.29)	7	0.188 (4.78)	671 (304)	. . .	9 600 (42.703)	15 700 (69.837)	24 500 (108.981)	35 000 (155.688)
9/16 (14.29)	19	0.113 (2.87)	637 (289)	. . .	9 640 (42.881)	16 100 (71.616)	24 100 (107.202)	33 700 (149.905)
5/8 (1.588)	7	0.207 (5.26)	813 (369)	. . .	11 600 (51.599)	19 100 (84.961)	29 600 (131.667)	42 400 (188.605)
5/8 (15.88)	19	0.125 (3.18)	796 (361)	. . .	11 000 (48.930)	18 100 (80.513)	28 100 (124.995)	40 200 (178.819)
3/4 (19.05)	19	0.150 (3.81)	1 155 (524)	. . .	16 000 (71.172)	26 200 (116.543)	40 800 (181.487)	58 300 (259.331)
7/8 (22.22)	19	0.177 (4.50)	1 581 (717)	. . .	21 900 (97.416)	35 900 (159.691)	55 800 (248.211)	79 700 (354.523)
1 (25.40)	19	0.200 (5.08)	2 073 (940)	. . .	28 700 (127.664)	47 000 (209.066)	73 200 (325.610)	104 500 (464.839)
1 (25.40)	37	0.143 (3.63)	2 057 (933)	. . .	28 300 (125.885)	46 200 (205.508)	71 900 (319.827)	102 700 (456.832)
1 1/8 (28.58)	37	0.161 (4.09)	2 691 (1 221)	. . .	36 000 (160.136)	58 900 (262.000)	91 600 (407.457)	130 800 (581.827)
1 1/4 (31.75)	37	0.179 (4.55)	3 248 (1 473)	. . .	44 600 (198.391)	73 000 (324.720)	113 600 (505.318)	162 200 (721.502)

[A] The Utilities Grade is used principally by communication and power and light industries.
[B] Refer to elongation requirements specified in Section 9.

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TABLE 2 Elongation Requirements for Grades of Strand

Grade of Strand	Elongation in 24 in. (610 mm), min, %
Utilities Grade (1)[A] and Common Strand	10
Utilities Grade (2)[A] and Siemens-Martin	8
Utilities Grade (3)[A] and High-Strength	5
Utilities Grade (4)[A] and Extra High-Strength	4

[A] See Table 1, Footnote B.

14. Adherence of Coating

14.1 The zinc-coated wire shall be capable of being wrapped at a rate not exceeding 15 turns/min in a close helix of at least two turns around a cylindrical mandrel equal to 3× the nominal diameter of the wire under test, without cracking or flaking the zinc coating to such an extent that any zinc can be removed by rubbing with the bare fingers.

NOTE 2—Loosening or detachment during the adhesion test of superficial, small particles of zinc formed by mechanical polishing of the surface of zinc-coated wire shall not be considered cause for rejection.

15. Ductility of Steel

15.1 The zinc-coated wire shall not fracture when wrapped at a rate not exceeding 15 turns/min in a close helix of at least 2 turns around a cylindrical mandrel. The mandrel diameter for testing Common and Siemens-Martin grade strand shall be equal to the nominal diameter of the individual wires of the strand. The mandrel diameter for Utilities, High-Strength, and Extra High-Strength grade strand, shall be equal to 3× the nominal diameter of the individual wires of the strand.

16. Finish

16.1 The zinc-coated wire shall be free of imperfections not consistent with good commercial practice. The zinc-coating shall be continuous and of reasonably uniform thickness.

17. Packaging and Marking

17.1 Wire strand shall be furnished in standard lengths (see 17.1.1) and in compact coils or on reels (see 17.1.2) as specified by the purchaser; otherwise lengths shall be as agreed upon at the time of purchase. Only one length of strand shall be furnished in each coil or on each reel. Lengths of strand may vary between the standard (nominal) length and 10 % over the standard (nominal) length, unless otherwise specified by the purchaser.

17.1.1 Standard lengths of strand are as follows: 250, 500, 1000, 2500, and 5000 ft (76, 152, 304, 760, and 1520 m).

TABLE 3 Permissible Variations in Diameter of Individual Zinc-Coated Wires

Nominal Diameter of Coated Wires in the Strand, in. (mm)	Permissible Variations, plus and minus, in. (mm)
0.041 to 0.060 (1.04 to 1.52)	0.002 (0.05)
0.061 to 0.090 (1.55 to 2.29)	0.003 (0.08)
0.091 to 0.120 (2.31 to 3.05)	0.004 (0.10)
0.121 and over (3.07 and over)	0.005 (0.13)

TABLE 4 Nominal Diameters and Minimum Weights of Coating for Zinc-Coated Steel Wires[A]

Nominal Diameter of Coated Wire in the Strand, in. (mm)	Minimum Weight of Coating, oz/ft² (g/m²) of Uncoated Wire Surface			
	Type 1[B]	Class A[C]	Class B[D]	Class C[D]
0.041 (1.04)	0.15 (46)	0.40 (122)	0.80 (244)	1.20 (366)
0.052 (1.32)	0.15 (46)	0.40 (122)	0.80 (244)	1.20 (366)
0.062 (1.57)	0.15 (46)	0.50 (153)	1.00 (305)	1.50 (458)
0.065 (1.65)	0.15 (46)	0.50 (153)	1.00 (305)	1.50 (458)
0.072 (1.83)	0.15 (46)	0.50 (153)	1.00 (305)	1.50 (458)
0.080 (2.03)	0.30 (92)	0.60 (183)	1.20 (366)	1.80 (549)
0.093 (2.36)	0.30 (92)	0.70 (214)	1.40 (427)	2.10 (641)
0.100 (2.54)	0.30 (92)	0.70 (214)	1.40 (427)	2.10 (641)
0.104 (2.64)	0.30 (92)	0.80 (244)	1.60 (488)	2.40 (732)
0.109 (2.77)	0.30 (92)	0.80 (244)	1.60 (488)	2.40 (732)
0.113 (2.87)	0.30 (92)	0.80 (244)	1.60 (488)	2.40 (732)
0.120 (3.05)	0.30 (92)	0.85 (259)	1.70 (519)	2.55 (778)
0.125 (3.18)	0.30 (92)	0.85 (259)	1.70 (519)	2.55 (778)
0.130 (3.30)	0.30 (92)	0.85 (259)	1.70 (519)	2.55 (778)
0.143 (3.63)	0.40 (122)	0.90 (275)	1.80 (549)	2.70 (824)
0.145 (3.68)	0.40 (122)	0.90 (275)	1.80 (549)	2.70 (824)
0.150 (3.81)	0.40 (122)	0.90 (275)	1.80 (549)	2.70 (824)
0.161 (4.09)	0.40 (122)	0.90 (275)	1.80 (549)	2.70 (824)
0.165 (4.19)	0.40 (122)	0.90 (275)	1.80 (549)	2.70 (824)
0.177 (4.50)	0.40 (122)	0.90 (275)	1.80 (549)	2.70 (824)
0.179 (4.55)	0.40 (122)	0.90 (275)	1.80 (549)	2.70 (824)
0.188 (4.78)	0.40 (122)	1.00 (305)	2.00 (610)	3.00 (915)
0.200 (5.08)	0.40 (122)	1.00 (305)	2.00 (610)	3.00 (915)
0.207 (5.26)	0.40 (122)	1.00 (305)	2.00 (610)	3.00 (915)

[A] For intermediate sizes of wire in the strand, the weight designations are the same as for the next finer size shown in this table.
[B] Type 1 (formerly "Galvanized") coating applies to "Common" Grade of strand only.
[C] Class A, "Extra Galvanized" and "Double Galvanized" are equivalent terms.
[D] Class A, Class B, and Class C coatings apply to all grades of strand.

17.1.2 Standard practice is to furnish all strand 7/16 in. (11.11 mm) and over in diameter on reels in lengths of 1000 ft (304 m) and over. Strand lengths of less than 1000 ft are regularly furnished in coils.

17.2 Each coil or reel shall have a strong weather-resistant tag securely fastened to it showing the length, nominal diameter, number of wires, grade of the strand, type, or class of coating, ASTM designation A 475, and the name or mark of the manufacturer. If additional information is required on the tag, it shall be so specified at the time of purchase.

18. Inspection

18.1 The manufacturer shall afford the inspector representing the purchaser all reasonable facilities to satisfy him that the material is being furnished in accordance with this specification. All tests and inspection shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

19. Rejection

19.1 If the wire or strand fails in the first test to meet any requirement of this specification, two additional tests shall be made on samples of wire or strand from the same coil or reel. If failure occurs in either of these tests, the lot of wire or strand shall be rejected.