



Standard Specification for Seamless Copper Bus Pipe and Tube¹

This standard is issued under the fixed designation B188; 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 U.S. Department of Defense.

^ε¹ NOTE—Table 10 was editorially corrected in April 2016.

1. Scope*

1.1 This specification establishes the requirements for seamless copper bus pipe and tube intended for use as electrical conductors.

1.1.1 The product shall be made from one of the following coppers, as denoted in the ordering information:²

| Copper UNS No. ² | Previously Used Designation | Type of Copper |
|-----------------------------|-----------------------------|---|
| C10100 | OFE | Oxygen-free, electronic |
| C10200 | OF | Oxygen-free without residual deoxidants |
| C10300 | — | Oxygen-free, extra low phosphorus |
| C10400, C10500, C10700 | OFS | Oxygen-free, silver bearing |
| C11000 | ETP | Electrolytic tough pitch |
| C11300, C11400, C11600 | STP | Silver-bearing tough pitch |
| C12000 | DLP | Phosphorized, low residual phosphorus |

1.2 Unless otherwise specified, any one of the above coppers may be furnished.

1.3 *Units*—The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units, which are provided for information only and are not considered standard.

2. Referenced Documents

2.1 *ASTM Standards*:³

B193 Test Method for Resistivity of Electrical Conductor Materials

¹ This specification is under the jurisdiction of ASTM Committee B05 on Copper and Copper Alloys and is the direct responsibility of Subcommittee B05.04 on Pipe and Tube.

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² The UNS system for copper and copper alloys (see Practice E527) is a simple expansion of the former standard designation system accomplished by the addition of a prefix “C” and a suffix “00.” The suffix can be used to accommodate composition variations of the base alloy.

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.

- [B428 Test Method for Angle of Twist in Rectangular and Square Copper and Copper Alloy Tube](#)
- [B577 Test Methods for Detection of Cuprous Oxide \(Hydrogen Embrittlement Susceptibility\) in Copper](#)
- [B601 Classification for Temper Designations for Copper and Copper Alloys—Wrought and Cast](#)
- [B846 Terminology for Copper and Copper Alloys](#)
- [E8/E8M Test Methods for Tension Testing of Metallic Materials](#)
- [E18 Test Methods for Rockwell Hardness of Metallic Materials](#)
- [E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications](#)
- [E53 Test Method for Determination of Copper in Unalloyed Copper by Gravimetry](#)
- [E62 Test Methods for Chemical Analysis of Copper and Copper Alloys \(Photometric Methods\) \(Withdrawn 2010\)⁴](#)
- [E243 Practice for Electromagnetic \(Eddy Current\) Examination of Copper and Copper-Alloy Tubes](#)
- [E255 Practice for Sampling Copper and Copper Alloys for the Determination of Chemical Composition](#)
- [E527 Practice for Numbering Metals and Alloys in the Unified Numbering System \(UNS\)](#)

3. Terminology

3.1 For definitions of terms related to copper and copper alloys, refer to Terminology B846.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *bus pipe or tube*—a high conductivity copper tubular product used as an electrical conductor.

4. Ordering Information

4.1 Include the following specified choices when placing orders for product under this specification, as applicable:

- 4.1.1 ASTM designation and year of issue,
- 4.1.2 Copper UNS designation (1.1.1 and 1.2),
- 4.1.3 Temper (Section 7),

⁴ The last approved version of this historical standard is referenced on www.astm.org.

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

- 4.1.4 Dimensions and form (Section 12),
- 4.1.5 Length (Section 12),
- 4.1.6 Quantity—total weight or total length or number of pieces of each size (Table 1),

4.2 The following options are available but may not be included unless specified at the time of placing the order when required:

- 4.2.1 Bend test (Section 10),
- 4.2.2 Hydrogen embrittlement susceptibility test (Section 10),
- 4.2.3 Microscopical examination (Section 10),
- 4.2.4 Tension testing (Section 9),
- 4.2.5 Eddy-current test (Section 11),
- 4.2.6 Certification (Section 21),
- 4.2.7 Test report (Section 22), and
- 4.2.8 If the specification number is required to be shown on the packaging (Section 23.2).

5. Materials and Manufacture

5.1 Material:

5.1.1 The material of manufacture shall be cast billet of one of the UNS copper alloy numbers included in the scope, and as so specified in the contract or purchase order, and shall be of such purity and soundness as to be suitable for processing into lengths of pipe or tube for the intended application.

5.2 Manufacture:

5.2.1 The product shall be manufactured by such hot-working, cold-working, and annealing processes as to produce a uniform, wrought, seamless structure in the finished product.

5.2.2 The method of manufacture shall be hot or cold working to the finished size, and subsequent annealing when required to meet the temper properties specified (see 7.1).

6. Chemical Composition

6.1 The material shall conform to the chemical composition requirements in Table 2 for the copper UNS No. designation specified in the ordering information.

6.2 These composition limits do not preclude the presence of other elements. By agreement between the manufacturer or supplier and purchaser, limits may be established and analysis required for unnamed elements.

7. Temper

7.1 The standard tempers for products described in this specification are given in Table 3 as defined in Classification B601.

7.1.1 *Soft Anneal*—O60.

7.1.2 *Hard Drawn*—H80.

TABLE 1 Dimensions and Weights of Copper Pipe, Nominal or Standard Pipe Sizes^A

| Nominal or Standard Pipe Size, in. | Dimensions, in. (mm) | | | Cross-Sectional Area of Wall, in. ² (mm ²) | Theoretical Weight, lb/ft (kg/m) |
|------------------------------------|----------------------|-----------------|----------------|---|----------------------------------|
| | Outside Diameter | Inside Diameter | Wall Thickness | | |
| Regular | | | | | |
| 1/4 | 0.540(13.7) | 0.376(9.55) | 0.082(2.08) | 0.118(0.761) | 0.457(0.680) |
| 3/8 | 0.675(17.1) | 0.495(12.6) | 0.090(2.29) | 0.165(1.06) | 0.641(0.954) |
| 1/2 | 0.840(21.3) | 0.626(15.9) | 0.107(2.72) | 0.246(1.59) | 0.955(1.42) |
| 3/4 | 1.050(26.7) | 0.822(20.9) | 0.114(2.90) | 0.335(2.16) | 1.30(1.93) |
| 1 | 1.315(33.4) | 1.063(27.0) | 0.126(3.20) | 0.471(3.04) | 1.82(2.71) |
| 1 1/4 | 1.660(42.2) | 1.368(34.7) | 0.146(3.71) | 0.694(4.48) | 2.69(4.00) |
| 1 1/2 | 1.900(48.3) | 1.600(40.6) | 0.150(3.81) | 0.825(5.32) | 3.20(4.76) |
| 2 | 2.375(60.3) | 2.063(52.4) | 0.156(3.96) | 1.09(7.03) | 4.22(6.28) |
| 2 1/2 | 2.875(73.0) | 2.501(63.5) | 0.187(4.75) | 1.58(10.2) | 6.12(9.11) |
| 3 | 3.500(88.9) | 3.062(77.8) | 0.219(5.56) | 2.26(14.6) | 8.75(13.0) |
| 3 1/2 | 4.000(102) | 3.500(88.9) | 0.250(6.35) | 2.95(19.0) | 11.4(17.0) |
| 4 | 4.500(114) | 4.000(102) | 0.250(6.35) | 3.34(21.5) | 12.9(19.2) |
| 5 | 5.562(141) | 5.062(129) | 0.250(6.35) | 4.17(26.9) | 16.2(24.1) |
| 6 | 6.625(168) | 6.125(156) | 0.250(6.35) | 5.01(32.3) | 19.4(28.9) |
| 8 | 8.625(219) | 8.001(203) | 0.312(7.92) | 8.15(52.6) | 31.6(47.0) |
| 10 | 10.750(273) | 10.020(255) | 0.365(9.27) | 11.9(76.8) | 46.2(68.7) |
| 12 | 12.750(324) | 12.000(305) | 0.375(9.52) | 14.6(94.2) | 56.5(84.1) |
| Extra Strong | | | | | |
| 1/4 | 0.540(13.7) | 0.294(7.47) | 0.123(3.12) | 0.161(1.04) | 0.625(0.930) |
| 3/8 | 0.675(17.1) | 0.421(10.7) | 0.127(3.23) | 0.219(1.41) | 0.847(1.26) |
| 1/2 | 0.840(21.3) | 0.542(13.8) | 0.149(3.78) | 0.323(2.08) | 1.25(1.86) |
| 3/4 | 1.050(26.7) | 0.736(18.7) | 0.157(3.99) | 0.440(2.84) | 1.71(2.54) |
| 1 | 1.315(33.4) | 0.951(24.2) | 0.182(4.62) | 0.648(4.18) | 2.51(3.73) |
| 1 1/4 | 1.660(42.2) | 1.272(32.3) | 0.194(4.93) | 0.893(5.76) | 3.46(5.15) |
| 1 1/2 | 1.900(48.3) | 1.494(37.9) | 0.203(5.16) | 1.08(6.97) | 4.19(6.23) |
| 2 | 2.375(60.3) | 1.933(49.1) | 0.221(5.61) | 1.50(9.68) | 5.80(8.63) |
| 2 1/2 | 2.875(73.0) | 2.315(58.8) | 0.280(7.11) | 2.28(14.7) | 8.85(13.2) |
| 3 | 3.500(88.9) | 2.892(73.6) | 0.304(7.72) | 3.05(19.7) | 11.8(17.6) |
| 3 1/2 | 4.000(102) | 3.358(85.3) | 0.321(8.15) | 3.71(23.9) | 14.4(21.4) |
| 4 | 4.500(114) | 3.818(97.0) | 0.341(8.66) | 4.46(28.8) | 17.3(25.7) |
| 5 | 5.562(141) | 4.812(122) | 0.375(9.52) | 6.11(39.4) | 23.7(35.3) |
| 6 | 6.625(168) | 5.751(146) | 0.437(11.1) | 8.50(54.8) | 32.9(49.0) |
| 8 | 8.625(219) | 7.625(194) | 0.500(12.7) | 12.8(82.6) | 49.5(73.7) |
| 10 | 10.750(273) | 9.750(248) | 0.500(12.7) | 16.1(104) | 62.4(92.9) |

^A 1 in.² = 1 270 000 cmil.

TABLE 2 Chemical Requirements

NOTE 1—If the type of silver-bearing copper is not specified (that is, whether tough-pitch, phosphorized, or oxygen-free) any one of the three types may be supplied at the option of the manufacturer.

| Element | Composition, % | | | | | | | | | | |
|---------------------------|---------------------|--------|--------------------|---------------------|---------------------|---------------------|--------|---------------------|---------------------|---------------------|-------------|
| | Copper UNS No. | | | | | | | | | | |
| | C10100 ^A | C10200 | C10300 | C10400 ^B | C10500 ^B | C10700 ^B | C11000 | C11300 ^C | C11400 ^C | C11600 ^C | C12000 |
| Copper (incl silver), min | 99.99 ^D | 99.95 | 99.95 ^E | 99.95 | 99.95 | 99.95 | 99.90 | 99.90 | 99.90 | 99.90 | 99.90 |
| Phosphorus | ^A | ... | 0.001–0.005 | ... | ... | ... | ... | ... | ... | ... | 0.004–0.012 |
| Oxygen, max. | 0.0005 | 0.0010 | ... | 0.0010 | 0.0010 | 0.0010 | ... | ... | ... | ... | ... |
| Silver | ^A | ... | ... | 8 ^F | 10 ^F | 25 ^F | ... | 8 ^F | 10 ^F | 25 ^F | ... |

^A Impurity maximums in ppm of C10100 shall be: antimony 4, arsenic 5, bismuth 1.0, cadmium 1, iron 10, lead 5, manganese 0.5, nickel 10, phosphorus 3, selenium 3, silver 25, sulfur 15, tellurium 2, tin 2, and zinc 1.

^B C10400, C10500, and C10700 are oxygen-free coppers with the addition of a specified amount of silver. The compositions of these alloys are equivalent to C10200 plus the intentional addition of silver.

^C C11300, C11400, C11500, and C11600 are electrolytic tough-pitch copper with silver additions. The compositions of these alloys are equivalent to C11000 plus the intentional addition of silver.

^D Copper shall be determined by difference between “impurity total” and 100 %.

^E Copper (includes silver) + phosphorus, min.

^F Values are minimum silver in troy ounces per avoirdupois ton (1 oz/ton is equivalent to 0.0034 %).

TABLE 3 Mechanical and Electrical Properties^A

| Temper Designation | | | Tensile Strength ksi (MPa) ^B | | Elongation in 2 in. (51 mm), min, % | | Bend Test Angle of Bend, ° | | Electrical Resistivity ^B max at 20°C (68°F), Ω·g/m ² | | | | Rockwell Hardness (F Scale) 60-kg Load 1/16-in. Ball |
|--------------------|-------------|---|--|----------|---|-----|----------------------------------|--|---|---------|--------|--|--|
| | | | | | | | | | Copper UNS No. | | | | |
| Code | Name | Classification and Size | min | max | | | C10100 | C10200, C10400, C10500, C10700, C11000, C11300, C11400, and C11600 | C10300 | C12000 | | | |
| O60 | Soft Anneal | All types, all sizes | ... | 37 (255) | 25 | 180 | 0.15176 | 0.15328 | 0.15614 | 0.17031 | 50 max | | |
| H80 | Hard Drawn | Rectangular or square: | | | | | | | | | | | |
| | | up to 6-in. (152-mm) major outside dimension, incl up to 3/16-in. (4.8-mm) wall thickness, incl | 35 (240) | ... | 8 | ... | 0.15585 | 0.15737 | 0.15940 | 0.17418 | 75 min | | |
| | | over 3/16-in. (4.8-mm) wall thickness | 33 (230) | ... | 15 | ... | 0.15521 | 0.15673 | 0.15940 | 0.17418 | 65 min | | |
| | | over 6-in. (152-mm) major outside dimension | 32 (220) | ... | 20 | ... | 0.15425 | 0.15577 | 0.15940 | 0.17418 | 65 min | | |
| | | Round (pipe and tube): | | | | | | | | | | | |
| | | up to 4-in. (102-mm) outside diameter, incl | 40 (275) | ... | 3 | 90 | 0.15713 | 0.15865 | 0.15940 | 0.17418 | 80 min | | |
| | | over 4-in. (102-mm) outside diameter | 38 (260) | ... | 6 | ... | 0.15585 | 0.15737 | 0.15940 | 0.17418 | 75 min | | |

^A See 6.1.

^B See Appendix X2.

8. Electrical Resistivity Requirements

8.1 The product furnished shall conform to the maximum electrical resistivity requirements prescribed in Table 3 when tested in accordance with Test Method B193.

9. Mechanical Property Requirements

9.1 Product furnished under this specification shall conform to the tensile and hardness property requirements prescribed in Table 3.

9.1.1 Tension testing for tensile and elongation information need not be performed except when specified by the purchaser at the time of placing the order (see 4.2.4).

9.1.2 The tension test shall be used to resolve cases of dispute.

10. Performance Requirements

10.1 Bend Test Requirements:

10.1.1 The product shall conform to the bend testing requirements prescribed in Table 3.

10.1.2 Bend testing need not be performed except when specified by the purchaser at the time of placing the order (see 4.2.1).

10.2 Microscopical Examination:

10.2.1 The test specimens of material designated as Copper UNS Nos. C10100, C10200, C10300, C10400, C10500, C10700, and C12000 shall be free of cuprous oxide as determined by Procedure A of Test Methods B577. In case of a dispute, a referee method in accordance with Procedure C shall be used.

10.2.2 The test need not be performed except when specified at the time of placing the order (see 4.2.3).

10.3 Hydrogen Embrittlement Susceptibility Test:

10.3.1 When tested, material designated as Copper UNS Nos. C10100, C10200, C10300, C10400, C10500, C10700, and C12000 shall pass the embrittlement test of Procedure B of Test Methods B577. The actual performance of this test is not mandatory under the terms of this specification unless specified in the ordering information (see 4.2.2). In case of dispute, a referee method in accordance with Procedure C of Test Methods B577 shall be employed.

11. Other Requirements

11.1 Nondestructive Testing:

11.1.1 When specified (see 4.2.5), the product shall be tested in the final size but may be tested before the final anneal or heat treatment, when these thermal treatments are required, unless otherwise agreed upon by the manufacturer or supplier and purchaser.

11.1.2 Eddy-Current Test—When specified, each piece of product from 1/8-in. (3.2-mm) up to and including 3 1/8-in. (79.4-mm) nominal outside diameter, or 2 1/2-in. (63.5-mm) distance between outside parallel surfaces, shall be subjected to an eddy-current test. Testing shall follow the procedures of Practice E243 except for determination of “end effect.” The product shall be passed through an eddy-current testing unit adjusted to provide information on the suitability of the product for the intended application.

11.1.3 Notch-depth standards rounded to the nearest 0.001 in. (0.025 mm) shall be 22 % of the nominal wall thickness. The notch depth tolerance shall be ±0.0005 in. (0.013 mm). Alternatively, when the test is performed using speed-insensitive equipment that can select a maximum imbalance signal, a maximum imbalance signal of 0.3 % shall be used.

11.1.4 Product that does not actuate the signaling device of the eddy-current test shall be considered as conforming to the requirements of this test. Product with discontinuities indicated by the testing unit may be reexamined or retested, at the option of the manufacturer, to determine whether the discontinuity is cause for rejection. Signals that are found to have been caused by minor mechanical damage, soil, or moisture shall not be cause for rejection of the product provided the dimensions of the product are still within prescribed limits and the product is suitable for its intended application.

12. Dimensions, Weights, and Permissible Variations

12.1 General—For the purpose of determining conformance with the dimensional requirements given in this specification, any measured value outside the specified limiting values for any dimension may be cause for rejection.

12.2 Dimensions and Weights—The dimensions and weights for nominal or standard copper pipe of various outside diameters shall be as prescribed in Table 1.

12.3 Weight Tolerances—The weight of the nominal or standard pipe shall not vary from the theoretical weight per foot prescribed in Table 1 by more than the following:

| Nominal or Standard Pipe Size, in. | Weight Tolerance, % |
|------------------------------------|---------------------|
| 6 and under | 5 |
| Over 6 to 8, incl | 7 |
| Over 8 | 8 |

12.4 Thickness Tolerances—The wall thickness of nominal or standard pipe at any point shall not be less than that prescribed in Table 1 by more than the following:

| Nominal or Standard Pipe Size, in. | Thickness Tolerance, % ^A |
|------------------------------------|-------------------------------------|
| 6 and under | 5 |
| Over 6 to 8, incl. | 7 |
| Over 8 | 8 |

^A Expressed to the nearest 0.001 in. (0.025 mm).

12.5 Copper Tube (Other than Pipe):

12.5.1 Round Tube—Wall thickness tolerances shall be in accordance with Table 4. Diameter tolerances shall be in accordance with Table 5.

TABLE 4 Wall Thickness Tolerances for Copper Tube (Not Applicable to Pipe)

NOTE 1—Maximum Deviation at Any Point: The following tolerances are plus and minus; if tolerances all plus or all minus are desired, double the values given.

| Wall Thickness, in. (mm) | Outside Diameter, in. (mm) | | | | | |
|--|-------------------------------------|-----------------------------------|---------------------------------|--------------------------------|-------------------------------|--------------------------------|
| | Over 1/8 (3.15) to 3/8 (15.9), incl | Over 5/8 (15.9) to 1 (25.4), incl | Over 1 (25.4) to 2 (50.8), incl | Over 2 (50.8) to 4 (102), incl | Over 4 (102) to 7 (178), incl | Over 7 (178) to 10 (254), incl |
| Up to 0.017 (0.432) incl | 0.001 (0.025) | 0.0015 (0.038) | 0.002 (0.051) | ... | ... | ... |
| Over 0.017 (0.432) to 0.024 (0.610) incl | 0.002 (0.051) | 0.002 (0.051) | 0.0025 (0.064) | ... | ... | ... |
| Over 0.024 (0.610) to 0.034 (0.864) incl | 0.0025 (0.064) | 0.0025 (0.064) | 0.003 (0.076) | 0.004 (0.10) | ... | ... |
| Over 0.034 (0.864) to 0.057 (1.45) incl | 0.003 (0.076) | 0.0035 (0.089) | 0.0035 (0.089) | 0.005 (0.13) | 0.007 (0.18) | ... |
| Over 0.057 (1.45) to 0.082 (2.08) incl | 0.0035 (0.089) | 0.004 (0.10) | 0.004 (0.10) | 0.006 (0.15) | 0.008 (0.20) | 0.010 (0.25) |
| Over 0.082 (2.08) to 0.119 (3.02) incl | 0.004 (0.10) | 0.005 (0.13) | 0.005 (0.13) | 0.007 (0.18) | 0.009 (0.23) | 0.011 (0.28) |
| Over 0.119 (3.02) to 0.164 (4.17) incl | 0.005 (0.13) | 0.006 (0.15) | 0.006 (0.15) | 0.008 (0.20) | 0.010 (0.25) | 0.012 (0.30) |
| Over 0.164 (4.17) to 0.219 (5.56) incl | 0.007 (0.18) | 0.0075 (0.19) | 0.008 (0.20) | 0.010 (0.25) | 0.012 (0.30) | 0.014 (0.36) |
| Over 0.219 (5.56) to 0.283 (7.19) incl | ... | 0.009 (0.23) | 0.010 (0.25) | 0.012 (0.30) | 0.014 (0.36) | 0.016 (0.41) |
| Over 0.283 (7.19) to 0.379 (9.63) incl | ... | 0.012 (0.30) | 5 ^A | 5 ^A | 6 ^A | 6 ^A |
| Over 0.379 (9.62) | ... | ... | 5 ^A | 5 ^A | 6 ^A | 6 ^A |

^A Percent of the specified wall expressed to nearest 0.001 in. (0.025 mm).

TABLE 5 Average Diameter Tolerances for Copper Tube

| Specified Diameter, in. (mm) | Diameter to Which Tolerance Applies ^A | Tolerance, plus and minus, in. (mm) |
|-----------------------------------|--|-------------------------------------|
| Up to 5/8 (15.9), incl | inside or outside | 0.002 (0.051) |
| Over 5/8 (15.9) to 1 (25.4), incl | inside or outside | 0.0025 (0.064) |
| Over 1 (25.4) to 2 (50.8), incl | inside or outside | 0.003 (0.076) |
| Over 2 (50.8) to 3 (76.2), incl | inside or outside | 0.004 (0.10) |
| Over 3 (76.2) to 4 (102), incl | inside or outside | 0.005 (0.13) |
| Over 4 (102) to 5 (127), incl | inside or outside | 0.006 (0.15) |
| Over 5 (127) to 6 (152), incl | inside or outside | 0.007 (0.18) |
| Over 6 (152) to 8 (203), incl | inside or outside | 0.008 (0.20) |
| Over 8 (203) to 10 (254), incl | inside or outside | 0.010 (0.25) |

^A The average outside diameter of a tube is the average of the maximum and minimum outside diameters, as determined at any one cross-section of the tube.

12.5.2 *Rectangular Including Square Tube*—Wall thickness tolerances shall be in accordance with Table 6. The tolerances on distance between parallel surfaces for rectangular and square tube in straight lengths only shall be in accordance with Table 7 and Fig. 1.

12.5.3 *Length and Length Tolerances*—Tube ordered to specific or stock lengths with or without ends shall conform to the tolerances prescribed in Table 8 and Table 9.

12.5.3.1 Pipe ordered to specific stock lengths with or without ends shall conform to tolerances prescribed in Table 10 and Table 11.

12.6 *Roundness*—For tube or pipe of H (drawn) tempers in straight lengths, the roundness tolerances shall be as follows:

| t/D (Ratio of Wall Thickness to Outside Diameter) | Roundness Tolerance, % of Outside Diameter (Expressed to the Nearest 0.001 in. (0.025 mm)) |
|---|--|
| 0.01 to 0.03 incl | 1.5 |
| Over 0.03 to 0.05, incl | 1.0 |
| Over 0.05 to 0.10, incl | 0.8 or 0.002 in. (0.51 mm), whichever is greater |
| Over 0.10 | 0.7 or 0.002 in. (0.51 mm), whichever is greater |

12.6.1 Compliance with the roundness tolerance shall be determined by taking measurements on the outside diameter only, irrespective of the manner in which the tube dimensions are specified.

12.6.2 The deviation from roundness is measured as the difference between major and minor diameters as determined at any one cross section of the tube.

TABLE 6 Wall Thickness Tolerances for Copper Rectangular and Square Tube

NOTE 1—Maximum deviation at any point. The following tolerances are plus and minus; if tolerances all plus or all minus are desired, double the values given.

| Wall Thickness, in. (mm) | Distance Between Outside Parallel Surface, in. ^A (mm) | | | | | | |
|--|--|-------------------------------------|-----------------------------------|---------------------------------|--------------------------------|-------------------------------|--------------------------------|
| | 1/32 (0.794) to 1/8 (3.18), incl | Over 1/8 (3.18) to 5/8 (15.9), incl | Over 5/8 (15.9) to 1 (25.4), incl | Over 1 (25.4) to 2 (50.8), incl | Over 2 (50.8) to 4 (102), incl | Over 4 (102) to 7 (178), incl | Over 7 (178) to 10 (254), incl |
| Up to 0.017 (0.432) incl | 0.002 (0.051) | 0.002 (0.051) | 0.0025 (0.064) | 0.003 (0.076) | ... | ... | ... |
| Over 0.017 (0.432) to 0.024 (0.610) incl | 0.003 (0.076) | 0.0025 (0.064) | 0.003 (0.076) | 0.0035 (0.089) | ... | ... | ... |
| Over 0.024 (0.610) to 0.034 (0.864) incl | 0.0035 (0.089) | 0.0035 (0.089) | 0.0035 (0.089) | 0.004 (0.10) | 0.006 (0.15) | ... | ... |
| Over 0.034 (0.864) to 0.057 (1.45) incl | 0.004 (0.10) | 0.004 (0.10) | 0.0045 (0.11) | 0.005 (0.12) | 0.007 (0.18) | 0.009 (0.23) | ... |
| Over 0.057 (1.45) to 0.082 (2.08) incl | ... | 0.005 (0.13) | 0.006 (0.15) | 0.007 (0.18) | 0.008 (0.20) | 0.010 (0.25) | 0.012 (0.30) |
| Over 0.082 (2.08) to 0.119 (3.02) incl | ... | 0.007 (0.18) | 0.008 (0.20) | 0.009 (0.23) | 0.010 (0.25) | 0.012 (0.30) | 0.014 (0.36) |
| Over 0.119 (3.02) to 0.164 (4.17) incl | ... | 0.009 (0.23) | 0.010 (0.25) | 0.011 (0.28) | 0.012 (0.30) | 0.014 (0.36) | 0.016 (0.41) |
| Over 0.164 (4.17) to 0.219 (5.56) incl | ... | 0.011 (0.28) | 0.012 (0.30) | 0.013 (0.33) | 0.015 (0.38) | 0.017 (0.43) | 0.019 (0.48) |
| Over 0.219 (5.56) to 0.283 (7.19) incl | ... | ... | 0.015 (0.38) | 0.016 (0.41) | 0.018 (0.46) | 0.020 (0.51) | 0.022 (0.56) |

^A In the case of rectangular tube, the major dimension determines the thickness tolerance applicable to all walls.

TABLE 7 Tolerances on Distance Between Parallel Surfaces for Copper Rectangular and Square Tube

NOTE 1—The following tolerances are plus and minus; if tolerances all plus or all minus are desired, double the values given.

| Dimensions a or b (Fig. 1), in. (mm) | Tolerances, in. (mm) |
|--------------------------------------|----------------------|
| Up to 1/8 (3.18), incl | 0.003 (0.076) |
| Over 1/8 to 5/8 (3.18 to 15.9), incl | 0.004 (0.10) |
| Over 5/8 to 1 (15.9 to 25.4), incl | 0.005 (0.13) |
| Over 1 to 2 (25.4 to 50.8), incl | 0.006 (0.15) |
| Over 2 to 3 (50.8 to 76.2), incl | 0.007 (0.18) |
| Over 3 to 4 (76.2 to 102), incl | 0.008 (0.20) |
| Over 4 to 5 (102 to 127), incl | 0.009 (0.23) |
| Over 5 to 6 (127 to 152), incl | 0.010 (0.25) |
| Over 6 to 8 (152 to 203), incl | 0.011 (0.28) |
| Over 8 to 10 (203 to 254), incl | 0.012 (0.30) |

Nominal dimension a determines tolerance applicable to both a and c.
Nominal dimension b determines tolerance applicable to both b and d.

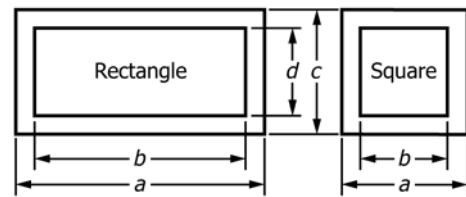


FIG. 1 Tolerances on Distance Between Parallel Surfaces for Copper Rectangular and Square Tube (Table 7)

12.6.3 No tolerances have been established for as-extruded tube, redrawn tube, annealed tube, any tube furnished in coils, or drawn tube whose wall thickness is under 0.016 in. (0.406 mm).

12.7 *Squareness of Cut*—For pipe and tube in straight lengths, the departure from squareness of the end of any pipe or tube shall not exceed the following:

12.7.1 *Pipe:*

| Specified Outside Diameter, in. (mm) | Tolerance |
|--------------------------------------|---|
| Up to 5/8 (15.9), incl | 0.010 in. (0.25 mm) |
| Over 5/8 (15.9) | 0.016 in./in. (0.016 mm/mm) of diameter |

TABLE 8 Length Tolerances for Tube

NOTE 1—Tolerances are all plus; if all minus tolerances are desired, use the same values; if tolerances plus and minus are desired, halve the values given.

| Length | Tolerances, in. (mm) Applicable Only to Full Length Pieces | | |
|--|--|--|--|
| | For Major Outside Dimensions up to 1 in. (25.4 mm), incl | For Major Outside Dimensions over 1 in. (25.4 mm) to 4 in. (102 mm) incl | For Major Outside Dimensions over 4 in. (102 mm) |
| Specific lengths: | | | |
| Up to 6 in. (152 mm), incl | 1/32 (0.79) | 1/16 (1.6) | |
| Over 6 in. (152 mm) to 2 ft (610 mm), incl | 1/16 (1.6) | 3/32 (2.4) | 1/8 (3.2) |
| Over 2 ft (610 mm) to 6 ft (1.83 m), incl | 3/32 (2.4) | 1/8 (3.2) | 1/4 (6.4) |
| Over 6 ft (1.83 m) to 14 ft (4.27 m), incl | 1/4 (6.4) | 1/4 (6.4) | 1/4 (6.4) |
| Over 14 ft (4.27 m) | 1/2 (13) | 1/2 (13) | 1/2 (13) |
| Specific lengths with ends | 1 (25) | 1 (25) | 1 (25) |
| Stock lengths with or without ends | 1 ^A (25) | 1 ^A (25) | 1 ^A (25) |

^A As stock lengths are cut and placed in stock in advance of orders, departure from this tolerance is not practicable.

TABLE 9 Schedule of Tube Lengths (Specific and Stock) with Ends

| Major Outside Dimensions, in. (mm) | Specific Length, ft (m) | Shortest Permissible Length, ^A % of Specific Length | Maximum Permissible Weight of Ends, % of Lot Weight |
|------------------------------------|-----------------------------|--|---|
| Up to 1 (25.4), incl | 6 (1.83) to 20 (6.10), incl | 70 | 20 |
| Over 1 (25.4) to 2 (50.8), incl | 6 (1.83) to 20 (6.10), incl | 60 | 25 |
| Over 2 (50.8) to 3 (76.2), incl | 6 (1.83) to 20 (6.10), incl | 55 | 30 |
| Over 3 (76.2) to 4 (102), incl | 6 (1.83) to 20 (6.10), incl | 50 | 40 |

^A Expressed to the nearest 1/2 ft (150 mm).

TABLE 10 Length Tolerances for Pipe Furnished in Straight Lengths^A

| Length | Tolerances, in. (mm) Applicable Only to Full-Length Pieces |
|---|--|
| Specific Lengths: | |
| Up to 6 in. (152 mm), incl | 1/16 (1.6) |
| Over 6 in. to 2 ft (152 to 610 mm), incl | 3/32 (2.4) |
| Over 2 to 6 ft (610 mm to 1.83 m), incl | 1/8 (3.2)† |
| Over 6 ft to 14 ft (1.83 m to 4.27 m), incl | 1/4 (6.4) |
| Over 14 ft (4.27 m) | 1/2 (13) |
| Specific lengths with ends | 1 (25) |
| Stock lengths with or without ends | 1 (25) |

† Editorially corrected.

^A As stock lengths are cut and placed in stock in advance of orders, departure from this tolerance is not practicable.

12.7.2 Round Tube:

| Specified Outside Diameter, in. (mm) | Tolerance |
|--------------------------------------|---|
| Up to 5/8 (15.9), incl | 0.010 in. (0.25 mm) |
| Over 5/8 (15.9) | 0.016 in./in. (0.016 mm/mm) of diameter |

12.7.3 Rectangular and Square Tube:

| Specified Distance Between Major Outside Parallel Surface | Tolerance |
|---|---|
| Up to 5/8 (15.9), incl | 0.016 in. (0.41 mm) |
| Over 5/8 (15.9) | 0.025 in./in. (0.025 mm/mm) of distance between outside parallel surfaces |

12.8 Straightness Tolerances:

12.8.1 Round Tubes—For round tubes of any drawn temper, 1/4 to 3 1/2 in. (6.35 to 88.9 mm) in outside diameter, inclusive, the straightness tolerances shall be in accordance with **Table 12**.

12.8.2 Rectangular and Square Tubes—For rectangular and square tubes of any drawn temper, the straightness tolerance shall be 1/2-in. (13-mm) maximum curvature (depth of arc) in any 6-ft (1.8-m) portion of the total length.

12.9 Unit Weight—For purpose of calculating weights, cross sections, and so forth, the density of the copper shall be taken as 0.323 lb/in.³ (8.94 g/cm³).

12.10 Corner Radius: Rectangular and Square Tubes—The permissible radii for commercially square corners shall be in accordance with **Table 13**.

12.11 Twist Tolerances: Rectangular and Square Tubes—The maximum twist about the longitudinal axis of drawn temper rectangular and square tubes shall not exceed 1°/ft (1°/305 mm) of length, measured to the nearest degree, and the total angle of twist shall not exceed 20° when measured in accordance with Test Method **B428**. The requirement is not applicable to tubes in the annealed temper or to tubes whose specified major dimension is less than 1/2 in. (12.7 mm).

13. Workmanship, Finish, and Appearance

13.1 The product shall be free of defects of a nature that would interfere with the intended application. It shall be well cleaned and free from dirt.

14. Sampling

14.1 The lot size, portion size, and sample size of the finished product shall be as follows:

14.1.1 Lot Size—An inspection lot shall be 10 000 lb (4540 kg) or portion thereof, subject to inspection at one time.

TABLE 11 Schedule of Pipe Lengths Specific and Stock with Ends Included

| Major Outside Dimensions, in. (mm) | Nominal Length, ft (m) | Shortest Permissible Length, ^A percent of Nominal Length | Maximum Permissible Weight of Ends, percent of Lot Weight |
|------------------------------------|------------------------------|--|--|
| Up to 3 (76.2), incl | 6 to 20 (1.85 to 6.10), incl | 55 | 30 |
| Over 3 to 3½ (76.2 to 88.9), incl | 6 to 20 (1.85 to 6.10), incl | 50 | 40 |

^A Expressed to the nearest ½ ft (150 mm).

TABLE 12 Straightness Tolerances for Tube^A in Any Drawn Temper

NOTE 1—Applies to round tube in any drawn temper from ¼ (6.35) to 3½ in. (88.9 mm), incl, in outside diameter.

| Length, ft ^B (m) | Maximum Curvature (Depth of Arc), in. (mm) |
|----------------------------------|---|
| Over 3 (0.914) to 6 (1.83), incl | ⅜ (4.8) |
| Over 6 (1.83) to 8 (2.44), incl | ⅝ (7.9) |
| Over 8 (2.44) to 10 (3.05), incl | ½ (13) |

^A Not applicable to pipe, redraw tube, and extruded tube or any annealed tube.
^B For lengths greater than 10 ft (3.05 m), the maximum curvature shall not exceed ½ in. (13 mm) in any 10-ft (3.05-m) portion of the total length.

TABLE 13 Permissible Radii for Commercially Square Corners for Rectangular and Square Tube

| Wall Thickness, in. (mm) | Maximum Radii, in. (mm) | |
|--|-------------------------|------------------|
| | Outside Corners | Inside Corners |
| Up to 0.058 (1.47), incl | ⅜ (1.2) | ½ (0.79) |
| Over 0.058 to 0.120 (1.47 to 3.03), incl | ⅜ (1.6) | ½ (0.79) |
| Over 0.120 to 0.250 (3.03 to 6.35), incl | ⅜ (2.4) | ½ (0.79) |
| Over 0.250 (6.35) | none established | none established |

14.1.2 *Portion Size*—A portion shall be taken to be representative of a lot according to the following schedule:

| Number of Pieces in Lot | Number of Pieces to be Taken ^A |
|-------------------------|---|
| 1 to 50 | 1 |
| 51 to 200 | 2 |
| 201 to 1500 | 3 |
| Over 1500 | 0.2 % of the total number of pieces in the lot, but not to exceed 10 pieces |

^A Each test portion shall be taken from a separate tube.

14.2 *Chemical Analysis*—Samples for chemical analysis shall be taken in accordance with Practice E255. Drillings, millings, and so forth shall be taken in approximately equal weight from each of the sample pieces selected in accordance with 15.1 and combined into one composite sample. The minimum weight of the composite sample shall be 150 g.

14.2.1 Instead of sampling in accordance with Practice E255, the manufacturer shall have the option of determining conformance to chemical composition as follows: Conformance shall be determined by the manufacturer by analyzing samples taken at the time the castings are poured or samples taken from the semi-finished product. If the manufacturer determines the chemical composition of the material during the course of manufacture, he shall not be required to sample and analyze the finished product. The number of samples taken for determination of chemical composition shall be as follows:

14.2.1.1 When samples are taken at the time the castings are poured, at least one sample shall be taken for each group of castings poured simultaneously from the same source of molten metal.

14.2.1.2 When samples are taken from the semi-finished product, a sample shall be taken to represent each 10 000 lb (4550 kg) or fraction thereof, except that not more than one sample shall be required per piece.

14.2.1.3 Due to the discontinuous nature of the processing of castings into wrought products, it is not practical to identify specific casting analysis with a specific quantity of finished material.

14.2.1.4 In the event that heat identification or traceability is required, the purchaser shall specify the details desired.

15. Number of Tests and Retests

15.1 Specimens taken from each sample piece selected in accordance with Section 14 shall be subjected to the Rockwell hardness test and to the electrical resistivity or conductivity test to determine conformance to the requirements prescribed in Table 3. The values for the Rockwell hardness number of each specimen shall be established by taking the arithmetical average of at least three readings.

15.2 One specimen taken from each sample piece shall be tested for tensile properties and one for bending, if required, to determine conformance to the requirements in Table 3.

15.3 In the case of coppers designated as oxygen-free or deoxidized, a section of each sample piece selected in accordance with Section 14 shall be submitted to microscopical examination as specified in Section 10.2 and also to the embrittlement test, if specified, as prescribed in Section 10.3.

15.4 Retests:

15.4.1 If any test specimen shows defective machining or develops flaws, it may be discarded and another specimen substituted.

15.4.2 If the percentage elongation of any tension test specimen is less than that specified and any part of the fracture is outside the middle two thirds of the gage length or in a punched or scribed mark within the reduced section, a retest on an additional specimen either from the same sample piece or from a new sample piece shall be allowed.

15.4.3 If a bend test specimen fails as a result of conditions of bending more severe than required by the specification, a retest shall be permitted on a new sample piece or on the remaining portion of the first sample piece.

15.4.4 If the results of the test on one of the specimens fail to meet the specified requirements, two additional specimens shall be taken from different sample pieces and tested. The results of the tests on both of these specimens shall meet the specified requirements. Failure of more than one specimen to meet the specified requirements for a particular property shall be cause for rejection of the entire lot.

16. Specimen Preparation

16.1 Chemical Analysis:

16.1.1 Preparation of the analytical specimens shall be the responsibility of the reporting laboratory.

16.2 *Tension Test Specimens:*

16.2.1 The test specimens shall be tested in full size when practicable and shall conform to the requirements of the “Test Specimen” section of Test Methods E8/E8M. If the limitation of the testing machine precludes the use of such a specimen, the test specimen conforming to Type No. 1 of Fig. 13 in Test Methods E8/E8M shall be used.

16.3 *Rockwell Hardness Test Specimens:*

16.3.1 The test specimen shall be of a size and shape to permit testing by the available equipment.

16.3.2 The surface of the test specimen shall be sufficiently flat and smooth so as to permit the accurate determination of hardness.

16.3.3 The test specimen shall be free from scale and foreign matter and care shall be taken to avoid any change in condition, that is, heating or cold work.

16.4 *Electrical Resistivity:*

16.4.1 Test specimen preparation shall be in accordance with the “Test Specimen” section of Test Method B193.

16.4.2 When the test specimen is taken from material in bulk, care shall be taken that the properties are not appreciably altered in the preparation.

16.5 *Bend Test Specimens:*

16.5.1 The bend test specimens shall be of a full diameter of tube, unless limitation of the testing machine precludes the use of such a specimen, in which case the specimen shall be machined to an acceptable size.

16.5.1.1 If a bend test specimen is machined, at least one of its original surfaces shall be retained. This surface shall constitute the outer periphery of the bend.

16.6 *Specimen for Microscopical Examination:*

16.6.1 The test specimen shall be prepared in accordance with Procedure A of Test Methods B577 and the specimen surface shall approximate a radial longitudinal section of round tube or a longitudinal section of rectangular or square tube perpendicular to, and bisecting, the major dimensional surface.

16.7 *Hydrogen Embrittlement Test Specimen:*

16.7.1 The test specimen shall conform to the appropriate requirements of Procedure B or C as required, of Test Methods B577.

17. Test Methods

17.1 *Chemical Analysis:*

17.1.1 In cases of disagreement, test methods for chemical analysis shall be subject to agreement between the manufacturer or supplier and the purchaser. The following table is a list of published methods, some of which may no longer be viable, which along with others not listed, may be used subject to agreement:

| Test | Method |
|---------------------------------|--------|
| Chemical Analysis of Copper | E53 |
| Chemical Analysis of Phosphorus | E62 |

17.1.2 Test method(s) to be followed for the determination of element(s) resulting from contractual or purchase order

agreement shall be as agreed upon between the manufacturer or supplier and the purchaser.

17.2 *Other Tests:*

17.2.1 The product furnished shall conform to specified requirements when subjected to test in accordance with the following table:

| Test | Method |
|---------------------------|--------|
| Electrical Resistivity | B193 |
| Microscopical Examination | B577 |
| Rockwell Hardness | E18 |
| Tension | E8/E8M |

17.2.2 *Bend Test*—When bend tests are made, the bend test specimen shall stand being bent cold through the angle prescribed in Table 3 without fracture on the outside of the bent portion. For nominal or standard pipe-size tubular sections, the bend shall be made on a radius in accordance with the following schedule:

| Nominal or Standard Pipe Size, in. | Mandrel Radius, in. (mm) |
|------------------------------------|--------------------------|
| 1/2 | 4.50 (114) |
| 3/4 | 5.00 (127) |
| 1 | 6.50 (165) |
| 1 1/4 | 8.00 (203) |
| 1 1/2 | 9.25 (235) |
| 2 | 10.75 (273) |
| 2 1/2 | 12.00 (305) |
| 3 | 14.75 (375) |
| 3 1/2 | 17.00 (432) |
| 4 | 18.25 (464) |

Other tubular sections shall be bent around a mandrel having a radius equal to six times the section dimension radial to the bend. Pipe and tube, before bending, may be filled with sand, rosin, or other suitable material.

17.2.2.1 When a bend test specimen is machined at least one of its original surfaces shall be retained. This surface shall constitute the outer periphery of the bend, which shall be made on a radius equal to that dimension of the machined specimen radial to the bend.

18. Significance of Numerical Limits

18.1 For purposes of determining compliance with the specified limits for requirements of the properties listed in the following table, an observed value or a calculated value shall be rounded as indicated in accordance with the rounding method of Practice E29.

| Property | Rounded Unit for Calculated or Observed Value |
|-------------------------|---|
| Chemical composition | nearest unit in the last right-hand place of figures of the specified limit |
| Hardness | |
| Electrical resistivity | nearest unit in the last right-hand place of figures |
| Electrical conductivity | |
| Tensile strength | nearest ksi (5 MPa) |
| Elongation: below 5 % | nearest multiple of 0.5 % |
| 5 % and over | nearest 1 % |

19. Inspection

19.1 The manufacturer, or supplier, shall inspect and make tests necessary to verify the furnished product conforms to specification requirements.

19.2 Source inspection of the product by the purchaser may be agreed upon between the manufacturer, or supplier, and the purchaser as part of the purchase order. In such case, the nature of the facilities needed to satisfy the inspector, representing the purchaser, that the product is being furnished in accordance with the specification shall be included in the agreement. All testing and inspection shall be conducted so as not to interfere unnecessarily with the operation of the works.

19.3 When mutually agreed upon, the manufacturer, or supplier, and the purchaser shall conduct the final inspection simultaneously.

20. Rejection and Rehearing

20.1 *Rejection:*

20.1.1 Product that fails to conform to the specification requirements when tested by the purchaser or purchaser's agent shall be subject to rejection.

20.1.2 Rejection shall be reported to the manufacturer or supplier promptly. In addition, a written notification of rejection shall follow.

20.1.3 In case of dissatisfaction with results of the test upon which rejection is based, the manufacturer, or supplier, shall have the option to make claim for a rehearing.

20.2 *Rehearing:*

20.2.1 As a result of product rejection, the manufacturer, or supplier, shall have the option to make claim for a retest to be conducted by the manufacturer, or supplier, and the purchaser. Samples of the rejected product shall be taken in accordance with the product specification and subjected to test by both parties using the test method(s) specified in the product specification, or alternately, upon agreement of both parties, an

independent laboratory may be selected for the test(s) using the test method(s) specified in the product specification.

21. Certification

21.1 When specified in the purchase order or contract, the purchaser shall be furnished certification that samples representing each lot have been either tested or inspected as directed in this specification and the requirements have been met.

22. Test Report

22.1 When specified in the purchase order or contract, a report of the test results shall be furnished.

23. Packing and Package Marking Requirements

23.1 *Packaging:*

23.1.1 The product shall be separated by size, composition, and temper and prepared for shipment in such a manner as to ensure acceptance by common carrier for transportation and to afford protection from the normal hazards of transportation.

23.2 *Package Marking:*

23.2.1 Each shipping unit shall be legibly marked with the purchase order number, alloy designation, temper, size, shape, and total length or piece count (for product furnished on a length basis) or both, or gross and net weights (for product furnished on a weight basis), and name of supplier.

23.2.2 When specified in the contract or purchase order, the specification number shall be shown.

24. Keywords

24.1 copper bus pipe; copper bus tube; electrical conductors; extra strong; regular; standard sizes; Copper UNS Nos. C10100; C10200; C10300; C10400; C10500; C10700; C11000; C11300; C11400; C11600; C12000

APPENDIXES

(Nonmandatory Information)

X1. RESISTIVITY

X1.1 "Resistivity" is used in place of "Conductivity." The value of $0.153\ 28\ \Omega\text{-g/m}^2$ at 20°C (68°F) is the international standard for the resistivity of annealed copper equal to 100 % conductivity. This term means that a wire 1 m in length and weighing 1 g would have a resistance of $0.153\ 28\ \Omega$. This is equivalent to a resistivity value of $875.20\ \Omega\text{-lb/mile}^2$, which signifies the resistance of a wire 1 mile in length weighing 1 lb. It is also equivalent, for example, to $1.7241\ \mu\Omega\text{-cm}$ of length of a bar $1\ \text{cm}^2$ in cross section. A complete discussion of this

subject is contained in *NBS Handbook 100* of the National Bureau of Standards.⁵ Relationships which may be useful in connection with the values of resistivity prescribed in this specification are as shown in **Table X1.1**, each column containing equivalent expressions, at 20°C (68°F).

⁵ *NBS Handbook 100*, NIST, is sold by the National Technical Information Service (NTIS), 5301 Shawnee Rd, Alexandria, VA 22312, <http://www.ntis.gov>.

TABLE X1.1 Resistivity Relationships

| Conductivity at 20°C (68°F), % | 101.0 | 100.0 | 98.40 | 98.16 | 97.80 | 97.40 | 96.60 | 96.16 | 90.0 | 88.0 |
|--------------------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| $\Omega\text{-g/m}^2$ | 0.151 76 | 0.153 28 | 0.155 77 | 0.156 14 | 0.156 73 | 0.157 37 | 0.158 65 | 0.159 40 | 0.170 31 | 0.174 18 |
| $\Omega\text{-lb/mile}^2$ | 868.53 | 875.20 | 889.42 | 891.60 | 894.90 | 898.55 | 905.86 | 910.15 | 972.44 | 994.55 |
| $\Omega\text{-cmil/ft}$ | 10.268 | 10.371 | 10.539 | 10.565 | 10.604 | 10.648 | 10.734 | 10.785 | 11.523 | 11.785 |
| $\Omega\text{-mm}^2/\text{m}$ | 0.017 070 | 0.017 241 | 0.017 521 | 0.017 564 | 0.017 629 | 0.017 701 | 0.017 845 | 0.017 930 | 0.019 156 | 0.019 592 |
| $\mu\Omega\text{-in.}$ | 0.672 07 | 0.678 79 | 0.689 81 | 0.691 51 | 0.694 06 | 0.696 90 | 0.702 57 | 0.705 90 | 0.754 21 | 0.771 35 |
| $\mu\Omega\text{-cm}$ | 1.7070 | 1.7241 | 1.7521 | 1.7564 | 1.7629 | 1.7701 | 1.7845 | 1.7930 | 1.9157 | 1.9592 |

X2. METRIC EQUIVALENTS

X2.1 The SI unit for strength properties now shown is in accordance with the International System of Units (SI). The derived SI unit for force is the newton (N), which is defined as that force which when applied to a body having a mass of one kilogram gives it an acceleration of one metre per second squared ($N = \text{kg}\cdot\text{m}/\text{s}^2$). The derived SI unit for pressure or

stress is the newton per square metre (N/m^2), which has been named the pascal (Pa) by the General Conference of Weights and Measures. Since $1 \text{ ksi} = 6\,894\,757 \text{ Pa}$, the metric equivalents are expressed as megapascal (MPa), which is the same as MN/m^2 and N/mm^2 .

SUMMARY OF CHANGES

Committee B05 has identified the principal changes to this specification that have been incorporated since the 2010 issue as follows:

(1) Editorial changes have been made in accordance with Guide B950.

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