



Standard Specification for Seamless Copper Bus Pipe and Tube¹

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

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 normally 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 Other coppers may be agreed upon between purchaser and supplier. Unless otherwise specified, any one of the above coppers may be furnished.

1.3 The values stated in inch-pound units are the standard. The values given in parentheses are for information only.

2. Referenced Documents

2.1 The following documents form a part of this specification to the extent referenced herein:

2.2 ASTM Standards:

B 193 Test Method for Resistivity of Electrical Conductor Materials³

B 428 Test Method for Angle of Twist in Rectangular and Square Copper and Copper Alloy Tube⁴

B 577 Test Methods for Detection of Cuprous Oxide (Hydrogen Embrittlement Susceptibility) in Copper⁴

B 601 Practice for Temper Designations for Copper and Copper Alloys—Wrought and Cast⁴

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 E 527) 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 *Annual Book of ASTM Standards*, Vol 02.03.

⁴ *Annual Book of ASTM Standards*, Vol 02.01.

E 8 Test Methods for Tension Testing of Metallic Materials⁵

E 18 Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials⁵

E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications⁶

E 53 Test Methods for Determination of Copper in Unalloyed Copper by Gravimetry⁷

E 62 Test Methods for Chemical Analysis of Copper and Copper Alloys (Photometric Methods)⁷

E 243 Practice for Electromagnetic (Eddy-Current) Examination of Copper and Copper-Alloy Tubes⁸

E 255 Practice for Sampling Copper and Copper Alloys for Determination of Chemical Composition⁷

E 527 Practice for Numbering Metals and Alloys (UNS)⁹

3. Terminology

3.1 Definitions:

3.1.1 *average diameter (for round tubes only), n*—the average of the maximum and minimum outside diameters, or maximum and minimum inside diameters, whichever is applicable, as determined at any one cross section of the tube.

3.1.2 *bus pipe or tube, n*—a high-conductivity copper tubular product used as an electrical conductor.

3.1.3 *lengths, n*—straight pieces of the product.

3.1.3.1 *lengths, ends, n*—straight pieces, shorter than the nominal length, left over after cutting the product into mill lengths, stock lengths, or specific lengths. They are subject to minimum length and maximum weight requirements.

3.1.3.2 *lengths, specific, n*—straight lengths that are uniform in length, as specified, and subject to established length tolerances.

3.1.3.3 *lengths, specific with ends, n*—specific lengths, including ends.

3.1.3.4 *lengths, standard, n*—uniform lengths recommended in a Simplified Practice Recommendation or established as a Commercial Standard.

3.1.3.5 *lengths, stock, n*—straight lengths that are mill cut and stored in advance of orders. They are usually 12 or 20 ft (3.66 or 6.10 m) and subject to established length tolerances.

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

⁶ *Annual Book of ASTM Standards*, Vol 14.02.

⁷ *Annual Book of ASTM Standards*, Vol 03.05.

⁸ *Annual Book of ASTM Standards*, Vol 03.03.

⁹ *Annual Book of ASTM Standards*, Vol 01.01.

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

3.1.3.6 *lengths, stock with ends, n*—stock lengths, including ends.

3.1.4 *tube, seamless, n*—a tube produced with a continuous periphery in all stages of the operations.

3.1.4.1 *pipe, n*—a seamless tube conforming to the particular nominal or standard pipe sizes, Table 1.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *capable of, adv*—The term “capable of” as used in this specification means that the test need not be performed by the producer of the material. However, should subsequent testing by the purchaser establish that the material does not meet these requirements, the material shall be subject to rejection.

4. Ordering Information

4.1 Orders for product under this specification should contain the following information:

- 4.1.1 ASTM designation and year of issue,
- 4.1.2 Copper UNS designation,
- 4.1.3 Temper (Section 7),
- 4.1.4 Dimensions and form (Section 14),
- 4.1.5 Length (Section 14),
- 4.1.6 Total length of each size,
- 4.1.7 Quantity of each item,

4.2 The following options are available under this specification and should be specified in the contract or purchase order when required:

- 4.2.1 Bend test (Section 10),
- 4.2.2 Cuprous oxide test (Section 12),
- 4.2.3 Microscopical examination (Section 11),
- 4.2.4 Tension testing (Section 9),
- 4.2.5 Eddy-current test (Section 13),
- 4.2.6 Certification (Section 23),
- 4.2.7 Mill test report (Section 24), and
- 4.2.8 Special packaging, if required (Section 25).

5. Materials and Manufacture

5.1 *Material:*

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

5.2 *Manufacture:*

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

5.2.2 The manufacture shall be such that the finished material conforms to the specified temper properties (see 7.1).

6. Chemical Composition

6.1 The material shall conform to the requirements in Table

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					
¼	0.540(13.7)	0.376(9.55)	0.082(2.08)	0.118(0.761)	0.457(0.680)
⅜	0.675(17.1)	0.495(12.6)	0.090(2.29)	0.165(1.06)	0.641(0.954)
½	0.840(21.3)	0.626(15.9)	0.107(2.72)	0.246(1.59)	0.955(1.42)
¾	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)
1¼	1.660(42.2)	1.368(34.7)	0.146(3.71)	0.694(4.48)	2.69(4.00)
1½	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)
2½	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)
3½	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					
¼	0.540(13.7)	0.294(7.47)	0.123(3.12)	0.161(1.04)	0.625(0.930)
⅜	0.675(17.1)	0.421(10.7)	0.127(3.23)	0.219(1.41)	0.847(1.26)
½	0.840(21.3)	0.542(13.8)	0.149(3.78)	0.323(2.08)	1.25(1.86)
¾	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)
1¼	1.660(42.2)	1.272(32.3)	0.194(4.93)	0.893(5.76)	3.46(5.15)
1½	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)
2½	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)
3½	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)

^A1 in.² = 1 270 000 cmil.

2 for the copper UNS no. designated in the ordering information.

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

7. Temper

7.1 The material shall be furnished in either the O60 (soft anneal) or H80 (hard drawn) temper as defined in Practice B 601. The requirements are specified in Table 3.

8. Electrical Resistivity Requirements

8.1 The material shall conform to the maximum electrical resistivity requirements prescribed in Table 3.

9. Mechanical Properties

9.1 The product shall conform to the mechanical requirements prescribed in Table 3.

9.1.1 Tension testing for tensile and elongation information need not be performed except when indicated 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.

9.2 All test specimens shall be tested in full size when practicable. When a machined specimen becomes necessary for any test required under this specification, enough metal shall be suitably removed from the sample to meet the limitations of the testing facilities.

10. Bend Test Requirements

10.1 The material shall conform to the bend testing requirements prescribed in Table 3.

10.1.1 Bend testing need not be performed except when indicated by the purchaser at the time of placing the order (see 4.2.4).

11. Microscopical Examination

11.1 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 Method B 577. In case of a dispute, a referee method in accordance with Procedure C shall be used.

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

12. Hydrogen Embrittlement Susceptibility Test

12.1 It is to be expected that material designated as Copper UNS Nos. C10100, C10200, C10300, C10400, C10500, C10700, and C12000 shall be capable of passing the embrittlement test of Procedure B of Test Method B 577. The actual performance of this test is not mandatory under the terms of this specification unless definitely specified in the ordering information. In case of a dispute, a referee method in accordance with Procedure C shall be used.

13. Nondestructive Testing

13.1 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.

13.2 *Eddy-Current Test*—When specified, each piece of product from 1/8 up to and including 3/8-in. nominal outside diameter, or 2 1/2-in. distance between outside parallel surfaces, shall be subjected to an eddy-current test. Testing shall follow the procedures of Practice E 243 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.

13.2.1 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.

13.2.2 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

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	...	...	...	...	...	...	...	0.004–0.0012
Oxygen, max.	0.0005	0.0010	...	0.0010	0.0010	0.0010	...	...	...	...	...
Silver	^A	...	...	^G	^F	^F	...	^F	^F	^F	...

^AImpurity 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.

^BC10400, C01500, 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.

^CC11300, 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.

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

^ECopper (includes silver) + phosphorus, min.

^FValues 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		Classification and Size	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
			min	max			Copper UNS No.				
Standard	Former						C10100	C10200, C10400, C10500, C10700, C11000, C11300, C11400, and C11600	C10300	C12000	
O60	Soft	All types, all sizes	...	37 (255)	25	180	0.15176	0.15328	0.15614	0.17031	50 max
H80	Hard	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

^ASee 6.1.

^BSee Appendix X2.

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.

14. Dimensions, Weights, and Permissible Variations

14.1 *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.

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

14.3 *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

14.4 *Thickness Tolerances*—The wall thickness of nominal or standard pipe at any point shall not be less than that prescribed in Table 3 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).

14.5 *Copper Tube (Other than Pipe)*:

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

14.5.2 *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.

14.5.3 *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.

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

14.6 *Roundness*—For drawn unannealed tube or pipe 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

14.6.1 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.

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

14.6.3 No tolerances have been established for as-extruded tube, redrawn tube, annealed tube, any tube furnished in coils,

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 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	0.001 (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

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

TABLE 5 Average Diameter Tolerances for Copper and Copper-Alloy 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)

^AThe 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.

or drawn tube whose wall thickness is under 0.016 in. (0.406 mm).

14.7 *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:

14.7.1 *Pipe:*

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

14.7.2 *Round Tube:*

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

14.7.3 *Rectangular and Square Tube:*

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

14.8 *Straightness Tolerances:*

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

14.8.2 *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.

14.9 *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).

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

14.11 *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 (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 B 428. The requirement is not applicable to tubes in the annealed temper or to tubes whose specified major dimension is less than 1/2 in.

15. Workmanship, Finish, and Appearance

15.1 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.

16. Sampling

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

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)

^AIn 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.

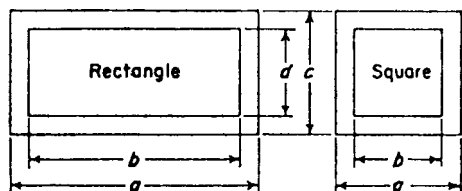


FIG. 1 Tolerances on Distance Between Parallel Surfaces for Copper Rectangular and Square Tube (Table 7)

16.1.1 Lot Size—An inspection lot shall be 5000 lb (2270 kg) or portion thereof, subject to inspection at one time.

16.1.2 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

^AEach test portion shall be taken from a separate tube.

17. Number of Tests and Retests

17.1 Chemical Analysis—Samples for chemical analysis shall be taken in accordance with Practice E 255. Drillings,

millings, and so forth shall be taken in approximately equal weight from each of the sample pieces selected in accordance with 17.1 and combined into one composite sample. The minimum weight of the composite sample that is to be divided into three equal parts shall be 150 g.

17.1.1 Instead of sampling in accordance with Practice E 255, 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 semifinished 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:

17.1.1.1 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.

17.1.1.2 When samples are taken from the semifinished 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.

17.1.1.3 Because of 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.

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

17.2 Specimens taken from each sample piece selected in accordance with Section 16 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.

17.3 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.

17.4 In the case of coppers designated as oxygen-free or

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)

^AAs 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

^AExpressed 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	1/3 (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)

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

deoxidized, a section of each sample piece selected in accordance with Section 16 shall be submitted to microscopical examination as specified in Section 11 and also to the embrittlement test, if specified, as prescribed in Section 12.

17.5 Retests:

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

17.5.2 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.

17.5.3 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.

17.5.4 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.

18. Specimen Preparation

18.1 Chemical Analysis:

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

18.2 Tension Test Specimens:

18.2.1 The test specimens shall be of the full section of the tube and shall conform to the requirements of the "Test Specimen" section of Test Methods E 8, unless the limitation of the testing machine precludes the use of such a specimen. In this case, the test specimen conforming to Type No. 1 of Fig. 13 in Test Methods E 8 shall be used.

18.3 Rockwell Hardness Test Specimens:

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

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

18.3.3 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.

18.4 Electrical Resistivity:

18.4.1 Test specimen preparation shall be in accordance with the "Test Specimen" section of Test Method B 193.

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

18.5 Bend Test Specimens:

18.5.1 The bend test specimens shall be of a full diameter of tube, unless limitation of the testing machine precludes the use

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

^AExpressed 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)

^ANot applicable to pipe, redraw tube, and extruded tube or any annealed tube.

^BFor 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)	⅜ (0.79)
Over 0.058 to 0.120 (1.47 to 3.03), incl	⅜ (1.6)	⅜ (0.79)
Over 0.120 to 0.250 (3.03 to 6.35), incl	⅜ (2.4)	⅜ (0.79)
Over 0.250 (6.35)	none established	none established

of such a specimen, in which case the specimen shall be machined to an acceptable size.

18.5.1.1 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.

18.6 Specimen for Microscopical Examination:

18.6.1 The test specimen shall be prepared in accordance with Procedure A of Test Method B 577 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.

18.7 Hydrogen Embrittlement Test Specimen:

18.7.1 The test specimen shall conform to the appropriate requirements of Procedure B of Test Method B 577.

19. Test Methods

19.1 The properties enumerated in this specification shall, in cases of dispute, be determined in accordance with the following applicable test methods:

Test	ASTM Designation
Chemical Analysis of Copper	E 53
Chemical Analysis of Phosphorus	E 62
Electrical Resistivity	B 193
Microscopical Examination	B 577
Rockwell Hardness	E 18
Tension	E 8

19.2 When bend tests are made, the bend test specimen shall stand being bent cold through the angle prescribed in Table 1 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)
½	4.50 (114)
¾	5.00 (127)
1	6.50 (165)
1¼	8.00 (203)
1½	9.25 (235)
2	10.75 (273)
2½	12.00 (305)
3	14.75 (375)
3½	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.

19.3 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.

20. Significance of Numerical Limits

20.1 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 E 29.

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 %

21. Inspection

21.1 The manufacturer shall inspect and make necessary tests to verify that the material furnished conforms to the requirements of this specification.

21.2 The manufacturer shall afford the inspector representing the purchaser, all reasonable facilities, without charge, to demonstrate satisfactorily that the material is being furnished in accordance with the specified requirements.

22. Rejection and Rehearing

22.1 Material that fails to conform to the requirements of this specification may be rejected. Rejection should be reported to the manufacturer or the supplier promptly and in writing. In case of dissatisfaction with the results of the test, the manufacturer or the supplier may make claim for a rehearing.

23. Certification

23.1 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.

24. Mill Test Report

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

25. Packing and Package Marking Requirements

25.1 The material 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.

25.2 Each shipping unit shall be legibly marked with the purchase order number, metal or alloy designation, temper size, shape, and total length or piece count (for material furnished on a length basis) or both, or gross and net weights (for material furnished on a pound basis), and name of supplier. The specification number shall be shown when specified.

26. Keywords

26.1 copper bus pipe; copper bus tube; electrical conductors; extra strong; regular; standard sizes

APPENDIXES

(Nonmandatory Information)

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
Ω·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
Ω·lb/mile ²	886.53	875.20	889.42	891.60	894.90	898.55	905.86	910.15	972.44	994.55
Ω·cmil/ft	10.268	10.371	10.539	10.565	10.604	10.648	10.734	10.785	11.523	11.785
Ω·mm ² /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
μΩ·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
μΩ·cm	1.7070	1.7241	1.7521	1.7564	1.7629	1.7701	1.7845	1.7930	1.9157	1.9592

X1. RESISTIVITY

X1.1 “Resistivity” is used in place of “Conductivity.” The value of 0.153 28 Ω·g/m² 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 Ω. This is equivalent to a resistivity value of 875.20 Ω·lb/mile², which signifies the resistance of a wire 1 mile in length weighing 1 lb. It is also equivalent, for example, to 1.7241 μΩ·cm of length of a bar 1 cm² in cross section. A complete discussion of this

subject is contained in *NBS Handbook 100* of the National Bureau of Standards.¹⁰ 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).

¹⁰ *NBS Handbook 100*, NIST is sold by the National Technical Information Service, 5285 Port Royal Rd., Springfield, VA 22161.

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 = kg·m/s²). The derived SI unit for pressure or

stress is the newton per square metre (N/m²), which has been named the pascal (Pa) by the General Conference of Weights and Measures. Since 1 ksi = 6 894 757 Pa, the metric equivalents are expressed as megapascal (MPa), which is the same as MN/m² and N/mm².

SUMMARY OF CHANGES

This section identifies the principle changes that have been incorporated since the 1996 issue as follows:

- (1) Table 2 was corrected and revised to clarify requirements.

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