Designation: B 111/B 111M – 08a

Standard Specification for Copper and Copper-Alloy Seamless Condenser Tubes and Ferrule Stock[1]

This standard is issued under the fixed designation B 111/B 111M; 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] establishes the requirements for seamless tube and ferrule stock of copper and various copper alloys up to 3⅛ in. [80 mm] inclusive, in diameter, for use in surface condensers, evaporators, and heat exchangers. The following coppers and copper alloys are specified:[3] (**Warning—**Mercury is a definite health hazard in use and disposal. (See 12.1.))

Copper or Copper Alloy UNS No.	Previously Used Designation	Description
C10100	OFE	Oxygen-free electronic
C10200	OF[A]	Oxygen-free without residual deoxidants
C10300	. . .	Oxygen-free, extra low phosphorus
C10800	. . .	Oxygen-free, low phosphorus
C12000	DLP[A]	Phosphorized, low residual phosphorus
C12200	DHP[A]	Phosphorized, high residual phosphorus
C14200	DPA[A]	Phosphorized, arsenical
C19200	. . .	Phosphorized, 1 % iron
C23000	. . .	Red Brass
C28000	. . .	Muntz Metal
C44300	. . .	Admiralty Metals, B, C, and D
C44400		
C44500		
C60800	. . .	Aluminum Bronze
C61300	. . .	. . .
C61400	. . .	Aluminum Bronze, D
C68700	. . .	Aluminum Brass, B
C70400	. . .	95-5 Copper-Nickel
C70600	. . .	90-10 Copper-Nickel
C70620	. . .	90-10 Copper-Nickel—Welding Grade
C71000	. . .	80-20 Copper-Nickel
C71500	. . .	70-30 Copper-Nickel
C71520	. . .	70-30 Copper-Nickel—Welding Grade
C71640	. . .	Copper-nickel-iron-manganese
C72200	. . .	. . .

[A] Designations listed in Classification B 224.

1.2 *Units*—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 shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.3 The following safety hazards caveat pertains only to the test methods portion, Section 19, 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 The following documents in the current issue of the *Annual Book of ASTM Standards* form a part of this specification to the extent referenced herein:

2.2 *ASTM Standards:* [4]

B 153 Test Method for Expansion (Pin Test) of Copper and Copper-Alloy Pipe and Tubing

B 154 Test Method for Mercurous Nitrate Test for Copper Alloys

B 170 Specification for Oxygen-Free Electrolytic Copper—Refinery Shapes

B 224 Classification of Coppers

B 846 Terminology for Copper and Copper Alloys

[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] For *ASME Boiler and Pressure Vessel Code* applications, see related Specification SB-111 in Section II of the Code.

[3] 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.

[4] 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.

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

B 858 Test Method for Ammonia Vapor Test for Determining Susceptibility to Stress Corrosion Cracking in Copper Alloys
E 8 Test Methods for Tension Testing of Metallic Materials
E 8M Test Methods for Tension Testing of Metallic Materials [Metric][5]
E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
E 53 Test Method for Determination of Copper in Unalloyed Copper by Gravimetry
E 54 Test Methods for Chemical Analysis of Special Brasses and Bronzes[5]
E 62 Test Methods for Chemical Analysis of Copper and Copper Alloys (Photometric Methods)
E 75 Test Methods for Chemical Analysis of Copper-Nickel and Copper-Nickel-Zinc Alloys
E 76 Test Methods for Chemical Analysis of Nickel-Copper Alloys[5]
E 112 Test Methods for Determining Average Grain Size
E 243 Practice for Electromagnetic (Eddy-Current) Examination of Copper and Copper-Alloy Tubes
E 255 Practice for Sampling Copper and Copper Alloys for the Determination of Chemical Composition
E 478 Test Methods for Chemical Analysis of Copper Alloys
E 527 Practice for Numbering Metals and Alloys in the Unified Numbering System (UNS)

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms relating to copper and copper alloys, refer to Terminology B 846.

3.2 *Definition of Term Specific to This Standard:*

3.2.1 *capable of*—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 Include the following information when placing orders for product under this specification:

4.1.1 ASTM Designation and year of approval (for example, ASTM B 111/B 111M – 04),

4.1.2 Copper or Copper Alloy UNS Designation (see Table 1),

4.1.3 Form (tube or ferrule stock),

4.1.4 Temper (see Temper section),

4.1.5 Dimensions, outside diameter, and wall thickness, whether minimum or nominal (Dimensions and Permissible Variations Section),

4.1.6 Quantity—total weight or total length or number of pieces of each size, and

4.1.7 If product is purchased for agencies of the U.S. Government (see the Supplementary Requirements Section).

4.2 The following options are available and should be specified at the time of placing of the order when required:

4.2.1 Tension Test required per ASME Boiler and Pressure Vessel Code, Mechanical Properties section.

4.2.2 Pressure test as an alternative to eddy current test (Nondestructive Testing Section).

4.2.3 If the cut ends of the tubes do not need to be deburred (Workmanship, Finish, and Appearance section).

4.2.4 If the product is to be subsequently welded (Table 1, Footnotes G and H).

4.2.5 Residual Stress Test—Ammonia Vapor Test or Mercurous Nitrate Test (Performance Requirements Section).

4.2.6 For Ammonia Vapor Test, risk level (pH value) if other than 10.

4.2.7 Heat identification or traceability details (Number of tests and Retests section).

4.2.8 Certification (Certification Section).

4.2.9 Mill Test Report (Mill Test Report Section).

4.2.10 If a subsequent thermal treatment after straightening is required (Temper section).

5. Materials and Manufacture

5.1 *Materials*—The material shall be of such quality and purity that the finished product shall have the properties and characteristics prescribed in this specification.

5.2 *Manufacture*—The product shall be produced by processes such as casting, extrusion, drawing, annealing, straightening, trimming, and other processes which may produce a seamless tube in the specified condition.

6. Chemical Composition

6.1 The product shall conform to the chemical requirements specified in Table 1.

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

6.2.1 *Copper Alloy UNS No. C19200*—Copper may be taken as the difference between the sum of all the elements analyzed and 100 %. When all the elements in Table 1 are analyzed, their sum shall be 99.8 % minimum.

6.2.2 For copper alloys in which copper is specified as the remainder, copper may be taken as the difference between the sum of all the elements analyzed and 100 %.

6.2.2.1 When all the elements in Table 1 are analyzed, their sum shall be as shown in the following table:

Copper Alloy UNS No.	Copper Plus Named Elements, % min
C60800	99.5
C61300	99.8
C61400	99.5
C70400	99.5
C70600 & C70620	99.5
C71000	99.5
C71500 & C71520	99.5
C71640	99.5
C72200	99.8

6.2.3 For copper alloys in which zinc is specified as the remainder, either copper or zinc may be taken as the difference between the sum of all the elements analyzed and 100 %.

[5] Withdrawn. The last approved version of this historical standard is referenced on www.astm.org.

TABLE 1 Chemical Requirements

Copper or Copper Alloy UNS No.	Composition, %											
	Copper[A]	Tin	Aluminum	Nickel, incl Cobalt	Lead, max	Iron	Zinc	Manganese	Arsenic	Antimony	Phosphorus	Chromium	Other Named Elements
C10100	99.99 min[B]	0.002 max	...	0.0010 max	0.0005 max	0.0010 max	0.0001 max	0.00005 max	0.0005 max	0.0004 max	0.0003 max	0.0001 max	[C]
C10200[D]	99.95 min	...	...	...	...	...	...	...	...	...	...	...	[D]
C10300	99.95 min[E]	...	...	...	...	...	...	...	...	...	0.001–0.005	...	...
C10800	99.95 min[E]	...	...	...	...	...	...	...	...	...	0.005–0.012	...	...
C12000	99.90 min	...	...	...	...	...	...	...	...	...	0.004–0.012	...	...
C12200	99.9 min	...	...	...	...	...	...	...	...	...	0.015–0.040	...	...
C14200	99.40 min	...	...	...	...	...	...	...	0.15–0.50	...	0.015–0.040	...	...
C19200	98.5 min	...	...	...	...	0.8–1.2	0.20 max	...	...	...	0.01–0.04	...	...
C23000	84.0–86.0	...	...	...	0.05	0.05 max	remainder	...	...	...	...	...	...
C28000	59.0–63.0	...	...	...	0.09	0.07 max	remainder	...	...	...	...	...	...
C44300	70.0–73.0	0.9–1.2	...	...	0.07	0.06 max	remainder	...	0.02–0.06	...	...	...	...
C44400	70.0–73.0	0.9–1.2	...	...	0.07	0.06 max	remainder	...	...	0.02–0.10	...	...	...
C44500	70.0–73.0	0.9–1.2	...	...	0.07	0.06 max	remainder	...	...	...	0.02–0.10	...	...
C60800	remainder	...	5.0–6.5	...	0.10	0.10 max	...	...	0.02–0.35	...	...	...	...
C61300	remainder	0.20–0.50	6.0–7.5	0.15 max	0.01	2.0–3.0	0.10 max	0.20 max	...	...	0.015 max	...	[F,G]
C61400	remainder	...	6.0–8.0	...	0.01	1.5–3.5	0.20 max	1.0 max	...	...	0.015 max	...	...
C68700	76.0–79.0	...	1.8–2.5	...	0.07	0.06 max	remainder	...	0.02–0.06	...	...	...	...
C70400	remainder	...	...	4.8–6.2	0.05	1.3–1.7	1.0 max	0.30–0.8	...	...	...	...	...
C70600	remainder	...	...	9.0–11.0	0.05	1.0–1.8	1.0 max	1.0 max	...	...	...	...	...
C70620	86.5 min	...	...	9.0-11.0	0.02	1.0-1.8	0.50 max	1.0 max	...	...	0.02 max	...	C.05 max S.02 max
C71000	remainder	...	...	19.0–23.0	0.05[H]	0.50–1.0	1.0 max[H]	1.0 max	...	...	[H]	...	[H]
C71500	remainder	...	...	29.0–33.0	0.05	0.40–1.0	1.0 max	1.0 max	...	...	...	...	...
C71520	65.0 min	...	...	29.0-33.0	0.02	0.40-1.0	0.50 max	1.0 max	...	...	0.02 max	...	C.05 max S.02 max
C71640	remainder	...	...	29.0–32.0	0.05[H]	1.7–2.3	1.0 max[H]	1.5–2.5	...	...	[H]	...	C.06 max S.03 max[H]
C72200	remainder	...	...	15.0–18.0	0.05[H]	0.50–1.0	1.0 max[H]	1.0 max	...	...	[H]	0.30–0.70	Si.03 max Ti.03 max[H]

[A] Copper (including silver).
[B] This value is exclusive of silver and shall be determined by difference of "impurity total" from 100 %. "Impurity total" is defined as the sum of sulfur, silver, lead, tin, bismuth, arsenic, antimony, iron, nickel, mercury, zinc, phosphorus, selenium, tellurium, manganese, cadmium, and oxygen present in the sample.
[C] Impurity maximums in ppm for C10100 shall be: antimony 4, arsenic 5, bismuth 1, cadmium 1, iron 10, lead 5, manganese 0.5, mercury 1, nickel 10, oxygen 5, phosphorus 3, selenium 3, silver 25, sulfur 15, tellurium 2, tin 2, and zinc 1.
[D] Oxygen in C10200 shall be 10 ppm max.
[E] Copper plus sum of named elements shall be 99.95 % min.
[F] Silicon shall be 0.10 % max.
[G] When the product is for subsequent welding applications and is so specified by the purchaser, chromium shall be 0.05 % max, cadmium 0.05 % max, zinc 0.05 % max, and zirconium 0.05 % max.
[H] When the product is for subsequent welding applications, and so specified by the purchaser, zinc shall be 0.50 % max, lead 0.02 % max, phosphorus 0.02 % max, sulfur 0.02 % max, and carbon 0.05 % max.

6.2.3.1 When all the elements in Table 1 are analyzed, their sum shall be as shown in the following table:

Copper Alloy UNS No.	Copper Plus Named Elements, % min
C23000	99.8
C28000	99.7
C44300	99.6
C44400	99.6
C44500	99.6
C68700	99.5

7. Temper

7.1 Tubes of Copper Alloy UNS Nos. C23000, C28000, C44300, C44400, C44500, C60800, C61300, C61400, C68700, and C71000 shall be furnished in the annealed (O61) temper unless otherwise specified on the purchase order.

7.2 Tubes of Copper Alloy UNS Nos. C71500, C71520, and C71640 shall be supplied in one of the following tempers as specified: (*1*) annealed (O61) or (*2*) drawn, and stress-relieved (HR50).

7.3 Tubes of Copper Alloy UNS Nos. C10100, C10200, C10300, C10800, C12000, C12200, and C14200 shall be supplied in any one of the following tempers, one of which shall be specified: (*1*) light-drawn (H55), (*2*) hard-drawn (H80), or (*3*) hard drawn and end annealed (HE80).

7.4 Tubes of Copper Alloy UNS No. C19200 shall be supplied in any one of the following tempers, one of which shall be specified: (*1*) annealed (O61), (*2*) light-drawn (H55), (*3*) hard-drawn (H80), or (*4*) hard-drawn, and end-annealed (HE80).

7.5 Tubes of Copper Alloy UNS Nos. C70400, C70600, C70620, and C72200 may be supplied in either light-drawn (H55) or annealed (O61) temper.

7.6 Tubes for ferrule stock shall be annealed sufficiently to be fully recrystallized.

7.7 *Optional Post-Straightening Thermal Treatment*—Some tubes, when subjected to aggressive environments, may have the potential for stress-corrosion cracking failure due to the residual stresses induced during straightening processing. For such applications, it is suggested that tubes of Copper Alloy UNS Nos. C23000, C28000, C44300, C44400, C44500, C60800, C61300, C61400, and C68700 be subjected to a stress-relieving thermal treatment subsequent to straightening.

If required, this must be specified on the purchase order or contract. Tolerances for roundness and length, and the condition of straightness, for tube so ordered, shall be to the requirements agreed upon between the manufacturer and the purchaser.

8. Mechanical Properties

8.1 Material specified to meet the requirements of the *ASME Boiler and Pressure Vessel Code* shall have tensile properties as prescribed in Table 2 or Table 3.

9. Grain Size for Annealed Tempers

9.1 Grain size shall be a standard requirement for all product in the annealed (O61) temper.

9.1.1 Samples of annealed-temper tubes selected for test shall be subjected to microscopical examination per Test Methods E 112 at a magnification of 75 diameters and shall show uniform and complete recrystallization.

9.1.2 Products other than of Copper Alloy UNS Nos. C19200 and C28000 shall have an average grain size within the limits of 0.010 to 0.045 mm. These requirements do not apply to tubes of light-drawn (H55), hard-drawn (H80), hard-drawn and end-annealed (HE80), or drawn and stress-relieved tempers (HR50).

10. Expansion Test

10.1 Tube specimens selected for test shall withstand the expansion shown in Table 4 when expanded in accordance with Test Method B 153. The expanded tube shall show no cracking or rupture visible to the unaided eye.

10.2 Hard-drawn tubes not end annealed are not subject to this test. When tubes are specified end annealed, this test is required and shall be performed on the annealed ends of the sampled tubes.

10.3 Tubes for ferrule stock are not subject to the expansion test.

11. Flattening Test

11.1 *Test Method*—Each test specimen shall be flattened in a press at three (3) places along the length, each new place to be rotated on its axis approximately one third turn from the last flattened area. Each flattened area shall be at least 2 in. in length. A flattened test-specimen shall allow a micrometer caliper set at three (3) times the wall thickness to pass freely over the flattened area. The flattened areas of the test specimen shall be inspected for surface defects.

11.2 During inspection, the flattened areas of the test-specimen shall be free of defects, but blemishes of a nature that do not interfere with the intended application are acceptable.

11.3 Tubes for ferrule stock are not subject to flattening test.

12. Residual Stress Test

12.1 A residual stress test, when specified in the purchase order, is required only for Copper Alloy UNS Nos. C23000, C28000, C44300, C44400, C44500, C60800, C61300, C61400, and C68700 and when not supplied in an annealed temper.

12.2 Unless otherwise specified, the producer shall have the option of testing the product to either the mercurous nitrate test, Test Method B 154, or the ammonia vapor test, Test Method B 858, as prescribed below.

TABLE 2 Tensile Requirements—Inch-Pound Values

NOTE—See Table 3 for tensile requirements—SI values.

Copper or Copper Alloy UNS No.	Temper Designation		Tensile Strength, min ksi[A]	Yield Strength,[B] min ksi[A]	Elongation in 2 in., min %
	Standard	Former			
C10100, C10200, C10300, C10800, C12000, C12200, C14200	H55	light-drawn	36	30	. . .
C10100, C10200, C10300, C10800, C12000, C12200, C14200	H80	hard-drawn	45	40	. . .
C19200	H55	light-drawn	40	35	. . .
C19200	H80	hard-drawn	48	43	. . .
C19200	O61	annealed	38	12	. . .
C23000	O61	annealed	40	12	. . .
C28000	O61	annealed	50	20	. . .
C44300, C44400, C44500	O61	annealed	45	15	. . .
C60800	O61	annealed	50	19	. . .
C61300, C61400	O61	annealed	70	30	. . .
C68700	O61	annealed	50	18	. . .
C70400	O61	annealed	38	12	. . .
C70400	H55	light-drawn	40	30	. . .
C70600, C70620	O61	annealed	40	15	. . .
C70600, C70620	H55	light-drawn	45	35	. . .
C71000	O61	annealed	45	16	. . .
C71500, C70520	O61	annealed	52	18	. . .
C71500, C70520					
Wall thicknesses up to 0.048 in., incl	HR50	drawn and stress-relieved	72	50	12
Wall thicknesses over 0.048 in.	HR50	drawn and stress-relieved	72	50	15
C71640	O61	annealed	63	25	. . .
C71640	HR50	drawn and stress relieved	81	58	. . .
C72200	O61	annealed	45	16	. . .
C72200	H55	light-drawn	50	30	. . .

[A] ksi = 1000 psi.
[B] At 0.5 % extension under load.

TABLE 3 Tensile Requirements—SI Values

NOTE—See Table 2 for tensile requirements—inch-pound values.

Copper or Copper Alloy UNS No.	Temper Designation		Tensile Strength, min MPa	Yield Strength,[A] min MPa	Elongation in 50 mm, min %
	Standard	Former			
C10100, C10200, C10300, C10800, C12000, C12200, C14200	H55	light-drawn	250	205	. . .
C10100, C10200, C10300, C10800, C12000, C12200, C14200	H80	hard-drawn	310	275	. . .
C19200	H55	light-drawn	275	240	. . .
C19200	H80	hard-drawn	330	295	. . .
C19200	O61	annealed	260	85	. . .
C23000	O61	annealed	275	85	. . .
C28000	O61	annealed	345	140	. . .
C44300, C44400, C44500	O61	annealed	310	105	. . .
C60800	O61	annealed	345	130	. . .
C61300, C61400	O61	annealed	480	205	. . .
C68700	O61	annealed	345	125	. . .
C70400	O61	annealed	260	85	. . .
C70400	H55	light-drawn	275	205	. . .
C70600, C70620	O61	annealed	275	105	. . .
C70600, C70620	H55	light-drawn	310	240	. . .
C71000	O61	annealed	310	110	. . .
C71500, C71520	O61	annealed	360	125	. . .
C71500, C71520:					
Wall thicknesses up to 1.2 mm incl	HR50	drawn and stress-relieved	495	345	12
Wall thicknesses over 1.2 mm.	HR50	drawn and stress-relieved	495	345	15
C71640	O61	annealed	435	170	. . .
C71640	HR50	drawn and stress relieved	560	400	. . .
C72200	O61	annealed	310	110	. . .
C72200	H55	light-drawn	345	310	. . .

[A] At 0.5 % extension under load.

TABLE 4 Expansion Requirements

Temper Designation		Copper or Copper Alloy UNS No.	Expansion of Tube Outside Diameter, in Percent of Original Outside Diameter
Standard	Former		
O61	annealed	C19200	30
		C23000	20
		C28000	15
		C44300, C44400, C44500	20
		C60800	20
		C61300, C61400	20
		C68700	20
		C70400	30
		C70600, C70620	30
		C71000	30
		C71500, C71520	30
		C71640	30
		C72200	30
H55	light-drawn	C10100, C10200, C10300, C10800, C12000, C12200	20
		C14200	20
		C19200	20
		C70400	20
		C70600, C70620	20
		C72200	20
HR50	drawn and stress relieved	C71500, C71520	20
		C71640	20
. . .	hard-drawn and end annealed	C10100, C10200, C10300, C10800, C12000, C12200, C14200	30

12.2.1 *Mercurous Nitrate Test*:

12.2.1.1 **Warning**—Mercury is a definite health hazard and therefore equipment for the detection and removal of mercury vapor produced in volatilization is recommended. The use of rubber gloves in testing is advisable.

12.2.1.2 The test specimens, cut 6 in. [150 mm] in length, shall withstand without cracking, an immersion in the standard mercurous nitrate solution prescribed in Test Method B 154. The test specimen shall include the finished tube end.

12.2.2 *Ammonia Vapor Test*:

12.2.2.1 The test specimens, cut 6 in. [150 mm] in length, shall withstand without cracking ,the ammonia vapor test as prescribed in Test Method B 858. For the purposes of this specification, unless otherwise agreed between purchaser and supplier, the risk level identified in the Annex of Method B 858, shall be specified as risk level (pH value) of 10.

13. Nondestructive Testing

13.1 Each tube shall be subjected to the eddy-current test in 13.1.1. Tubes may be tested in the final drawn, annealed, or

heat-treated temper or in the drawn temper before the final anneal or heat treatment unless otherwise agreed upon by the supplier and the purchaser. The purchaser may specify either of the tests in 13.1.2 or 13.1.3 as an alternative to the eddy-current test.

13.1.1 *Eddy-Current Test*—Each tube shall be passed through an eddy-current testing unit adjusted to provide information on the suitability of the tube for the intended application. Testing shall follow the procedures of Practice E 243.

13.1.1.1 The depth of the round-bottom transverse notches and the diameters of the drilled holes in the calibrating tube used to adjust the sensitivity of the test unit are shown in Tables 5 and 6, and Tables 7 and 8, respectively.

13.1.1.2 Tubes that do not actuate the signaling device of the eddy-current tester shall be considered to conform to the requirements of this test. Tubes causing irrelevant signals because of moisture, soil, and like effects may be reconditioned and retested. Such tubes, when retested to the original test parameters, shall be considered to conform if they do not cause output signals beyond the acceptable limits. Tubes causing irrelevant signals because of visible and identifiable handling marks may be retested by the hydrostatic test prescribed in 13.1.2, or the pneumatic test prescribed in 13.1.3. Tubes meeting requirements of either test shall be considered to conform if the tube dimensions are within the prescribed limits, unless otherwise agreed upon between the manufacturer and the purchaser.

13.1.2 *Hydrostatic Test*—Each tube shall stand, without showing evidence of leakage, an internal hydrostatic pressure sufficient to subject the material to a fiber stress of 7000 psi [48 MPa] as determined by the following equation for thin hollow cylinders under tension. The tube need not be tested at a hydrostatic pressure of over 1000 psi [7.0 MPa] unless so specified.

$$P = 2St/(D - 0.8t)$$

where:

P = hydrostatic pressure, psig [MPa];
t = thickness of tube wall, in. [mm];
D = outside diameter of the tube, in. [mm]; and
S = allowable stress of the material, psi [MPa].

13.1.3 *Pneumatic Test*—Each tube shall be subjected to an internal air pressure of 60 psig [400 kPa], min, for 5 s without showing evidence of leakage. The test method used shall permit easy visual detection of any leakage, such as by having the tube under water or by the pressure differential method. Any evidence of leakage shall be cause for rejection.

TABLE 5 Notch Depth—Inch-Pound Values

NOTE—See Table 6 for notch depth—SI values.

Tube Wall Thickness, in.	Tube Outside Diameter, in.		
	Over ¼ to ¾, incl	Over ¾ to 1¼, incl	Over 1¼ to 3⅛, incl
Over 0.017–0.032	0.005	0.006	0.007
Incl 0.032–0.049	0.006	0.006	0.0075
Incl 0.049–0.083	0.007	0.0075	0.008
Incl 0.083–0.109	0.0075	0.0085	0.0095
Incl 0.109–0.120	0.009	0.009	0.011

TABLE 6 Notch Depth—SI Values

NOTE—See Table 5 for notch depth—inch-pound values.

Tube Wall Thickness, mm	Tube Outside Diameter, mm		
	Over 6 to 19, incl	Over 19 to 32, incl	Over 32 to 80, incl
Over 0.4–0.8	0.13	0.15	0.18
Incl 0.8–1.3	0.15	0.15	0.19
Incl 1.3–2.1	0.18	0.19	0.20
Incl 2.1–2.8	0.19	0.22	0.24
Incl 2.8–3.0	0.23	0.23	0.28

TABLE 7 Diameter of Drilled Holes—Inch-Pound Values

NOTE—See Table 8 for diameter of drilled holes—SI values.

Tube Outside Diameter, in.	Diameter of Drilled Holes, in.	Drill No.
¼ –¾ , incl	0.025	72
Over ¾ –1, incl	0.031	68
Over 1–1¼ , incl	0.036	64
Over 1¼ –1½ , incl	0.042	58
Over 1½ –1¾ , incl	0.046	56
Over 1¾ –2, incl	0.052	55

TABLE 8 Diameter of Drilled Holes—SI Values

NOTE—See Table 7 for diameter of drilled holes—inch-pound values.

Tube Outside Diameter, mm	Diameter of Drilled Holes, mm	Drill No.
6.0–19.0, incl	0.65	72
Over 19.0–25.4, incl	0.80	68
Over 25.4–31.8, incl	0.92	64
Over 31.8–38.1, incl	1.1	58
Over 38.1–44.4, incl	1.2	56
Over 44.4–50.8, incl	1.3	55

14. Dimensions and Permissible Variations

14.1 *Diameter*—The outside of the tubes shall not vary from that specified by more than the amounts shown in Table 9 or Table 10 as measured by "go" and "no-go" ring gages.

14.2 *Wall Thickness Tolerances:*

14.2.1 *Tubes Ordered to Minimum Wall*—No tube wall at its thinnest point shall be less than the specified wall thickness. The maximum plus deviation from the specified wall at any point shall not exceed twice the values shown in Tables 11 and 12.

14.2.2 *Tubes Ordered to Nominal Wall*—The maximum plus and minus deviation from the nominal wall at any point shall not exceed the values shown in Tables 11 and 12.

14.3 *Length*—The length of the tubes shall not be less than that specified when measured at a temperature of 20°C, but may exceed the specified value by the amounts given in Tables 13 and 14.

14.4 *Squareness of Cut*—The departure from squareness of the end of the tube shall not exceed the following:

Tube, Outside Diameter, in. [mm]	Tolerance, in. [mm]
Up to ⅝ [16], incl	0.010 in. [0.25]
Over ⅝ [16]	0.016 in./in. [mm/mm] of diameter

14.5 For the purpose of determining conformance with the dimensional requirements prescribed in this specification, any

TABLE 9 Diameter Tolerances—Inch-Pound Values

NOTE—See Table 10 for diameter tolerances—SI values.

Outside Diameter, in.	Wall Thickness, in.				
	0.020[A] 0.022 0.025 0.028	0.032	0.035	0.042	0.049 and Over
	Diameter Tolerance, Plus and Minus, in.				
Up to 0.500, incl	0.003	0.0025	0.0025	0.0025	0.0025
Over 0.500–0.740, incl	0.0040	0.004	0.004	0.0035	0.003
Over 0.740–1.000, incl	0.0060	0.006	0.005	0.0045	0.004
Over 1.000–1.250, incl	. . .	0.009	0.008	0.006	0.0045
Over 1.250–1.375, incl	. . .	. . .	. . .	0.008	0.005
Over 1.375–2.000, incl	. . .	. . .	. . .	. . .	0.006
Over 2.000–3.125, incl	. . .	. . .	. . .	. . .	0.0065

[A] Tolerances in this column are applicable to light drawn and drawn tempers only. Tolerances for annealed tempers shall be as agreed upon between the manufacturer and the purchaser.

TABLE 10 Diameter Tolerances—SI Values

NOTE—See Table 9 for diameter tolerances—inch-pound values.

Outside Diameter, mm	Wall Thickness, mm				
	0.508[A] 0.559 0.635 0.711	0.813	0.889	1.07	1.24 and Over
	Diameter Tolerance, Plus and Minus, mm				
Up to 12, incl	0.076	0.064	0.064	0.064	0.064
Over 12–18, incl	0.10	0.10	0.10	0.089	0.076
Over 18–25, incl	0.15	0.15	0.13	0.11	0.10
Over 25–35, incl	. . .	. . .	. . .	0.20	0.13
Over 35–50, incl	. . .	. . .	. . .	. . .	0.15
Over 50–79, incl	. . .	. . .	. . .	. . .	0.17

[A] Tolerances in this column are applicable to light drawn and drawn tempers only. Tolerances for annealed tempers shall be as agreed upon between the manufacturer and the purchaser.

TABLE 11 Wall Thickness Tolerances, Plus and Minus—Inch-Pound Values

NOTE—See Table 12 for SI values.

Wall Thickness, in.	Outside Diameter, in.			
	Over 1/8 to 5/8, incl	Over 5/8 to 1, incl	Over 1 to 2, incl	Over 2 to 3.125, incl
0.020, incl to 0.032	0.003	0.003	. . .	. . .
0.032, incl to 0.035	0.003	0.003	0.004	. . .
0.035, incl to 0.058	0.004	0.0045	0.0045	0.005
0.058, incl to 0.083	0.0045	0.005	0.005	0.0055
0.083, incl to 0.120	0.005	0.0065	0.0065	0.0065
0.120, incl to 0.134	0.007	0.007	0.0075	0.008

TABLE 12 Wall Thickness Tolerances, Plus and Minus—SI Values

NOTE—See Table 11 for inch-pound values.

Wall Thickness, mm	Outside Diameter, mm		
	Over 12 to 25, incl	Over 25 to 50, incl	Over 50 to 80, incl
0.50, incl to 0.80	0.08	. . .	. . .
0.80, incl to 0. 90	0.08	0.10	. . .
0.90, incl to 1.5	0.11	0.11	0.13
1.5, incl to 2.1	0.13	0.13	0.14
2.1, incl to 3.0	0.17	0.17	0.17
3.0, incl to 3.4	0.18	0.19	0.20

measured value outside the specified limiting values for any dimensions may be cause for rejection.

15. Workmanship, Finish and Appearance

15.1 Roundness, straightness, uniformity of the wall thickness, and inner and outer surface of the tube shall be such as to make it suitable for the intended application. Unless otherwise specified on the purchase order, the cut ends of the tubes shall be deburred by use of a rotating wire wheel or other suitable tool.

15.2 Annealed-temper or thermally stress-relieved tubes shall be clean and smooth but may have a superficial, dull iridescent film on both the inside and the outside surface. Drawn-temper tubes shall be clean and smooth, but may have a superficial film of drawing lubricant on the surfaces.

16. Sampling

16.1 *Sampling*—The lot size, portion size, and selection of sample pieces shall be as follows:

16.1.1 *Lot Size*—600 tubes or 10 000 lb [4550 kg] or fraction of either, whichever constitutes the greater weight.

16.1.2 *Portion Size*—Sample pieces from two individual lengths of finished product.

16.2 Samples taken for the purpose of the tests prescribed in the specification shall be selected in a manner that will represent correctly the material furnished and avoid needless

TABLE 13 Length Tolerances—Inch-Pound Values

NOTE—See Table 14 for SI values.

Specified Length, ft	Tolerance, all Plus, in.
Up to 15	3/32
Over 15–20, incl	1/8
Over 20–30, incl	5/32
Over 30–60, incl	3/8
Over 60–100, incl[A]	1/2

[A] Condenser tubes in lengths over 100 ft are not in present demand. Tolerance values for the lengths will be developed as experience dictates. Tolerance values for lengths in wall thicknesses of 0.020, incl. to 0.032 shall be as agreed upon between the manufacturer or supplier and the purchaser.

TABLE 14 Length Tolerances—SI Values

NOTE—See Table 13 for inch-pound values.

Specified Length, mm	Tolerance, all Plus, mm
Up to 4500	2.4
Over 4500–6000, incl	3.2
Over 6000–10 000, incl	4.0
Over 10 000–18 000, incl	9.5
Over 18 000–30 000, incl[A]	13.0

[A] Condenser tubes in lengths over 30 000 mm are not in present demand. Tolerance values for the lengths will be developed as experience dictates. Tolerance values for lengths in wall thicknesses of 0.5, inclusive to 0.8 shall be as agreed upon between the manufacturer or supplier and the purchaser.

destruction of finished material when samples representative of the material are available from other sources.

16.3 *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 16.1.2 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.

16.3.1 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:

16.3.1.1 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.

16.3.1.2 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.

16.3.1.3 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.

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

17. Number of Tests and Retests

17.1 *Test*:

17.1.1 *Chemical Analysis*—Chemical composition shall be determined as per the element mean of the results from at least two replicate analyses of the sample(s).

17.1.2 *Other Tests*—For tests specified in Sections 8-12 inclusive, specimens shall be taken from each of the pieces selected in accordance with 16.1.2.

17.1.3 If any test specimen representing a lot fails to conform to the requirements of Sections 6-12, two additional specimens, at the option of the manufacturer, may be taken as before, and submitted for check analysis or subjected to any tests in which the original specimen failed, but each of these specimens shall conform to the requirements specified.

17.2 *Retest*:

17.2.1 When requested by the manufacturer or supplier, a retest shall be permitted when results of tests obtained by the purchaser fail to conform to the requirements of the product specification.

17.2.2 The retest shall be as directed in the product specification for the initial test, except the number of test specimens shall be twice that normally required for the specified test.

17.2.3 All test specimens shall conform to the product specification requirement(s) in retest. Failure to conform shall be cause for rejection.

18. Specimen Preparation

18.1 *Flattening Test*—A test specimen shall be cut to a length that will allow the tube to be flattened at three (3) places along the length, with each flattened area to be at least 2 in. [50 mm] in length. When the temper is other than annealed, the sample may be annealed prior to testing.

18.2 *Expansion Test*—Prepare specimen as per Test Method B 153.

18.3 *Mercurous Nitrate Test*—Prepare specimen as per Test Method B 154.

18.4 *Ammonia Vapor Test*—Prepare specimen as per Test Method B 858.

18.5 *Chemical Analysis*—Prepare specimens as per Test Method E 478.

18.6 *Microscopical Examination*—Prepare specimens per Test Methods E 112.

18.6.1 The surface of the test specimen for microscopical examination shall approximate a radial longitudinal section of the tube.

18.7 *Tension Testing*—Tubes selected for test shall be subjected to the tension test which shall, in case of disagreement, be made in accordance with Test Methods E 8 [or E 8M]. Tension test specimen shall be of the full section of the tube and shall conform to the requirements of the section, Specimens for Pipe and Tube, of Test Methods E 8 [or E 8M], unless the limitations of the testing machine preclude the use of such a specimen. Test specimens conforming to Type No. 1 of Fig. 13, Tension Test Specimens for Large-Diameter Tubular Products, of Test Methods E 8 [or E 8M] may be used when a full section specimen cannot be tested.

19. Test Methods

19.1 The properties and chemical compositions enumerated in this specification shall, in case of disagreement, be determined in accordance with the following ASTM methods:

Test	ASTM Designation
Chemical analysis	B 170,[A] E 53, E 54, E 62, E 75, E 76, E 478
Grain size	E 112
Expansion (pin test)	B 153
Mercurous nitrate	B 154
Tension	E 8
Nondestructive test	E 243

[A] Reference to Specification B 170 is to the suggested chemical methods in the annex thereof. When E01 Committee has tested and published methods for assaying the low-level impurities in copper, the Specification B 170 annex will be eliminated.

19.2 Whenever tension test results are obtained from both full-size and machined specimens and they differ, the results obtained from full-size test specimens shall be used to determine conformance to the specification requirements.

19.3 Tension test results on material covered by this specification are not seriously affected by variations in speed of testing. A considerable range of testing speed is permissible; however, the range of stressing to the yield strength should not exceed 100 ksi/min [690 MPa/min]. Above the yield strength the movement per minute of the testing machine head under load should not exceed 0.5 in./in. [mm/mm] of gage length (or distance between grips for full-section specimens).

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, and for dimensional tolerances, 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 Observed or Calculated Value
Chemical composition	nearest unit in the last right-hand significant digit used in expressing the limiting value
Tensile strength Yield strength	nearest ksi, for over 10 to 100 ksi, incl [nearest 5 MPa]
Elongation	nearest 1 %
Grain size—under 0.060 mm	nearest multiple of 0.005 mm
0.060 mm and over	nearest 0.01 mm

21. Inspection

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

21.2 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.

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

22. Rejection and Rehearing

22.1 *Rejection*:

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

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

22.1.3 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.

22.2 *Rehearing*:

22.2.1 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.

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 requirements have been met.

23.2 When identified in the ordering information that product is purchased for *ASME Boiler and Pressure Vessel Code* applications, certification to this specification is mandatory.

24. Mill Test Report

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

25. Packaging and Package Marking

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, total length or piece count, or both, and name of supplier. The specification number shall be shown, when specified.

26. Keywords

26.1 condenser tube; copper; copper alloys; evaporator; ferrule stock; heat exchanger; seamless tube; UNS No. C10100; UNS No. C10200; UNS No. C10300; UNS No. C10800; UNS No. C12000; UNS No. C12200; UNS No. C14200; UNS No. C19200; UNS No. C23000; UNS No. C28000; UNS No. C44300; UNS No. C44400; UNS No. C44500; UNS No. C60800; UNS No. C61300; UNS No. C61400; UNS No. C68700; UNS No. C70400; UNS No. C70600; UNS No. C70620; UNS No. C71000; UNS No. C71500; UNS No. C71520; UNS No. C71640; UNS No. C72200

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirements shall apply only when specified by the purchaser in the inquiry, contract, or order, for agencies of the U.S. government.

S1. **Referenced Documents**

S1.1 The following documents of the issue in effect on date of material purchase form a part of this specification to the extent referenced herein:

S1.1.1 *Federal Standards:*[6]

Fed. Std. No. 102 Preservation, Packaging and Packing Levels

Fed. Std. No. 123 Marking for Shipment (Civil Agencies)

Fed. Std. No. 185 Identification Marking of Copper and Copper-Base Alloy Mill Products

S1.1.2 *Military Standard:*[6]

MIL-STD-129 Marking for Shipment and Storage

S1.1.3 *Military Specification:* [4]

B 900 Specification for Packaging of Copper and Copper Alloy Mill Products for U.S. Government Agencies

S2. **Quality Assurance**

S2.1 *Responsibility for Inspection*—Unless otherwise specified in the contract or purchase order, the manufacturer is responsible for the performance of all inspection and test requirements specified. Except as otherwise specified in the contract or purchase order, the manufacturer may use his own or any other suitable facilities for the performance of the inspection and test requirements unless disapproved by the purchaser at the time the order is placed. The purchaser shall have the right to perform any of the inspections or tests set forth when such inspections and tests are deemed necessary to assure that the material conforms to prescribed requirements.

S3. **Identification Marking**

S3.1 All material shall be properly marked for identification in accordance with Fed. Std. No. 185 except that the ASTM specification number and the alloy number shall be used.

S4. **Preparation for Delivery**

S4.1 *Preservation, Packaging, Packing:*

S4.1.1 *Military Agencies*—The material shall be separated by size, composition, grade or class and shall be preserved and packaged, Level A or C, packed Level A, B, or C as specified in the contract or purchase order, in accordance with the requirements of ASTM B 900.

S4.1.2 *Civil Agencies*—The requirements of Fed. Std. No. 102 shall be referenced for definitions of the various levels of packaging protection.

S4.2 *Marking:*

S4.2.1 *Military Agencies*—In addition to any special marking required by the contract or purchase order, marking for shipment shall be in accordance with MIL-STD-129.

S4.2.2 *Civil Agencies*—In addition to any special marking required by the contract or purchase order, marking for shipment shall be in accordance with Fed. Std. No. 123.

[6] Available from Standardization Documents Order Desk, DODSSP, Bldg. 4, Section D, 700 Robbins Ave., Philadelphia, PA 19111-5098, http://www.dodssp.daps.mil.

APPENDIX

(Nonmandatory Information)

X1. DENSITY OF COPPER AND COPPER ALLOYS

X1.1 The densities of the alloys covered by this specification are given in Table X1.1.

TABLE X1.1 Densities

NOTE—This information is for reference only.

Copper or Copper Alloy UNS No.	Density, lb/in.^{3}	Density, g/cm^3
C10100, C10200, C10300, C10800, C12000, C12200, C14200	0.323	8.94
C19200	0.320	8.86
C23000	0.316	8.75
C28000	0.303	8.39
C44300, C44400, C44500	0.308	8.53
C60800	0.295	8.17
C61300, C61400	0.285	7.89
C68700	0.301	8.33
C70400	0.323	8.94
C70600, C70620	0.323	8.94
C71000	0.323	8.94
C71500, C71520	0.323	8.94
C71640	0.323	8.94
C72200	0.323	8.94

SUMMARY OF CHANGES

Committee B05 has identified the location of selected changes to this standard since the last issue (B 111/B 111M – 08) that may impact the use of this standard. (Approved Oct. 1, 2008.)

(*1*) Changed lead level for Alloy C28000 from .30 % max to .09 % max.

Committee B05 has identified the location of selected changes to this standard since the last issue (B 111/B 111M – 04) that may impact the use of this standard. (Approved April 1, 2008.)

(*1*) Revised section 12.1.