This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

Designation: B111/B111M – 18a

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

This standard is issued under the fixed designation B111/B111M; 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.

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]

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
C15630	. . .	Nickel Phosphorus
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 B224.

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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.* (**Warning—**Mercury has been designated by many regulatory agencies as a hazardous substance that can cause serious medical issues. Mercury, or its vapor, has been demonstrated to be hazardous to health and corrosive to materials. Use caution when handling mercury and mercury-containing products. See the applicable product Safety Data Sheet (SDS) for additional information. The potential exists that selling mercury or mercury-containing products, or both, is prohibited by local or national law. Users must determine legality of sales in their location.)

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

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:

[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.

Current edition approved Oct. 1, 2018. Published October 2018. Originally approved in 1937. Last previous edition approved in 2018 as B111/B111M–18. DOI: 10.1520/B0111_B0111M–18A.

[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 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.

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

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2.2 *ASTM Standards:*[4]

B153 Test Method for Expansion (Pin Test) of Copper and Copper-Alloy Pipe and Tubing

B154 Test Method for Mercurous Nitrate Test for Copper Alloys

B170 Specification for Oxygen-Free Electrolytic Copper—Refinery Shapes

B224 Classification of Coppers

B846 Terminology for Copper and Copper Alloys

B858 Test Method for Ammonia Vapor Test for Determining Susceptibility to Stress Corrosion Cracking in Copper Alloys

B968/B968M Test Method for Flattening of Copper and Copper-Alloy Pipe and Tube

E8/E8M Test Methods for Tension Testing 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

E54 Test Methods for Chemical Analysis of Special Brasses and Bronzes (Withdrawn 2002)[5]

E62 Test Methods for Chemical Analysis of Copper and Copper Alloys (Photometric Methods) (Withdrawn 2010)[5]

E75 Test Methods for Chemical Analysis of Copper-Nickel and Copper-Nickel-Zinc Alloys (Withdrawn 2010)[5]

E76 Test Methods for Chemical Analysis of Nickel-Copper Alloys (Withdrawn 2003)[5]

E112 Test Methods for Determining Average Grain Size

E118 Test Methods for Chemical Analysis of Copper-Chromium Alloys (Withdrawn 2010)[5]

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

E478 Test Methods for Chemical Analysis of Copper Alloys

E527 Practice for Numbering Metals and Alloys in the Unified Numbering System (UNS)

E2575 Standard Test Method for Determination of Oxygen in Copper and Copper Alloys (Withdrawn 2017)[5]

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms relating to copper and copper alloys, refer to Terminology B846.

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 or Copper Alloy UNS No. Designation (see Table 1);

4.1.3 Temper (Section 7);

4.1.4 Dimensions, outside diameter, and wall thickness, whether minimum or nominal (Section 14);

4.1.5 How furnished (tube or ferrule stock);

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

4.1.7 Intended application.

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

4.2.1 Tension Test per ASME Boiler and Pressure Vessel Code (see Section 8).

4.2.2 Hydrostatic or pneumatic test as an alternative to eddy current test (Section 13).

4.2.3 If the cut ends of the tubes do not need to be deburred (Section 15).

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 (Section 12).

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

4.2.7 Heat identification or traceability details.

4.2.8 Certification (Section 23).

4.2.9 Test Report (Section 24).

4.2.10 If a subsequent thermal treatment after straightening is required (Section 7).

4.2.11 If product is purchased for agencies of the U.S. Government (see Supplementary Requirements section of this specification for additional requirements, if required).

5. Materials and Manufacture

5.1 *Materials:*

5.1.1 The material of manufacture shall be a form of such purity and soundness as to be suitable for processing into the products prescribed herein.

5.1.2 When specified in the contract or purchase order that heat identification or traceability is required, the purchaser shall specify the details desired.[6]

5.2 *Manufacture:*

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

5.2.2 The product shall be hot- or cold-worked to the finished size, and subsequently annealed, when required, to meet the temper properties specified.

6. Chemical Composition

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

[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.

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

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

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TABLE 1 Chemical Requirements

Copper or Copper Alloy UNS No.	Composition, %												
	Copper	Tin	Aluminum	Nickel, incl Cobalt	Lead, max	Iron	Zinc	Manganese	Arsenic	Antimony	Phosphorus	Chromium	Other Named Elements
C10100	99.99 min[A]	0.0002 max	...	0.0010 max[B]	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[C]	99.95 min[D]	...	...	...	...	...	...	...	...	...	...	...	[C]
C10300	99.95 min[D]	...	...	...	...	...	...	...	...	...	0.001–0.005	...	...
C10800	99.95 min[D]	...	...	...	...	...	...	...	...	...	0.005–0.012	...	...
C12000[E]	99.90 min[D]	...	...	...	...	...	...	...	...	...	0.004–0.012	...	...
C12200	99.9 min[D]	...	...	...	...	...	...	...	...	...	0.015–0.040	...	...
C14200	99.4 min[D]	...	...	...	...	...	...	...	0.15–0.50	...	0.015–0.040	...	...
C15630	remainder	...	...	0.60–0.90[B]	...	...	...	...	...	...	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[D]	...	5.0–6.5	...	0.10	0.10 max	...	...	0.02–0.35	...	...	...	...
C61300	remainder[D]	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[D]	...	6.0–8.0	...	0.01	1.5–3.5	0.20 max	1.0 max	...	...	0.015 max	...	...
C68700	76.0–79.0[D]	...	1.8–2.5	...	0.07	0.06 max	remainder	...	0.02–0.06	...	...	...	...
C70400	remainder[D]	...	...	4.8–6.2	0.05	1.3–1.7	1.0 max	0.30–0.8	...	...	...	...	...
C70600	remainder[D]	...	...	9.0–11.0	0.05	1.0–1.8	1.0 max	1.0 max	...	...	...	...	...
C70620	86.5 min[D]	...	...	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[D]	...	...	19.0–23.0	0.05[H]	0.50–1.0	1.0 max[H]	1.0 max	...	...	[H]	...	[H]
C71500	remainder[D]	...	...	29.0–33.0	0.05	0.40–1.0	1.0 max	1.0 max	...	...	...	...	...
C71520	65.0 min[D]	...	...	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[D]	...	...	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[D]	...	...	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] 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.
[B] Not including Cobalt.
[C] Additional impurity maximums in percent for alloy C10100 shall be: bismuth 0.0001, cadmium 0.0001, oxygen 0.0005, selenium 0.0003, sulfur 0.0015, tellurium 0.0002, mercury 0.0001. For C10200, oxygen should be 0.0010 max.
[D] Copper (including silver).
[E] This includes oxygen-free Cu which contains P in an amount agreed upon.
[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.

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

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

6.2.2 For alloys in which copper is listed as "remainder," copper is the difference between the sum results of all the elements determined and 100 %. When all elements in Table 1 are determined, the sum of the results shall be as follows:

Copper Alloy UNS No.	Copper Plus Named Elements, % min
C15630	99.5
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 alloys in which zinc is listed as the remainder, either copper or zinc may be taken as the difference between the sum of all the elements determined and 100 %. When all elements in Table 1 are determined, the sum of the results shall be as follows:

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 shall be furnished in the temper designations identified in Tables 2 and 3.

7.1.1 Drawn tempers H55 and H80.

7.1.2 Annealed temper O61.

7.1.3 Drawn and stress-relieved temper HR50.

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

7.3 *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

TABLE 2 Tensile Requirements—Inch-Pound Values

NOTE 1—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 %
	Code	Name			
C10100, C10200, C10300, C10800, C12000, C12200, C14200	H55	light-drawn	36	30	. . .
C10100, C10200, C10300, C10800, C12000, C12200, C14200	H80	hard-drawn	45	40	. . .
C15630	O61	annealed	30	8	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, C71520	O61	annealed	52	18	. . .
C71500, C71520					
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	45	. . .

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

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TABLE 3 Tensile Requirements—SI Values

NOTE 1—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 %
	Code	Name			
C10100, C10200, C10300, C10800, C12000, C12200, C14200	H55	light-drawn	250	205	. . .
C10100, C10200, C10300, C10800, C12000, C12200, C14200	H80	hard-drawn	310	275	. . .
C15630	O61	annealed	205	55	40
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.

contract. Tolerances for roundness and length, and the condition of straightness, for tube so ordered, shall meet the requirements agreed upon by 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 the standard requirement for all product in the annealed (O61) temper.

9.1.1 Other than Copper Alloy UNS Nos. C19200 and C28000, acceptance or rejection for all annealed products shall depend only on average grain size of the test specimen within the limits of 0.010 to 0.045 mm taken from each of two sample portions, and each specimen shall be within the limits prescribed herein when determined in accordance with Test Methods E112.

10. Performance Requirements

10.1 *Expansion Test:*

10.1.1 Tube specimens selected for test shall withstand the expansion shown in Table 4 when expanded in accordance with Test Method B153. 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 inspected per Test Method B968/B968M.

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 B154, or the ammonia vapor test, Test Method B858, as prescribed below.

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 B154. The test specimen shall include the finished tube end.

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TABLE 4 Expansion Requirements

Temper Designation		Copper or Copper Alloy UNS No.	Expansion of Tube Outside Diameter, in Percent of Original Outside Diameter
Code	Name		
O61	annealed	C15630	40
		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

12.2.2 *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 B858. For the purposes of this specification, unless otherwise agreed between purchaser and supplier, the risk level identified in the Annex of Method B858, 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 E243.

13.1.1.1 The depth of the round-bottom transverse notches or 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. Notches of less depth and smaller diameter drilled holes are acceptable to meet this requirement.

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

TABLE 5 Notch Depth—Inch-Pound Values

NOTE 1—See Table 6 for notch depth—SI values.

Tube Wall Thickness, in.	Tube Outside Diameter, in.		
	Over 1/4 to 3/4, incl	Over 3/4 to 1 1/4, incl	Over 1 1/4 to 3 1/8, 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 1—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

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TABLE 7 Diameter of Drilled Holes—Inch-Pound Values

NOTE 1—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 1—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

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.

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. Alternatively, micrometers may be used to ensure outer diameter tolerance at any one point; however, in cases of dispute, ring gauges shall be used for final determination.

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 room temperature, 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 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.

TABLE 9 Diameter Tolerances—Inch-Pound Values

NOTE 1—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.

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TABLE 10 Diameter Tolerances—SI Values

NOTE 1—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 1—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 1—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

TABLE 13 Length Tolerances—Inch-Pound Values

NOTE 1—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 demand at present. 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 1—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 demand at present. 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.

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 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 E255. 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 Alternatively to sampling procedures 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 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:

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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 at the time of order placement.

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*—Prepare specimen as per Test Method B968/B968M.

18.2 *Expansion Test*—Prepare specimen as per Test Method B153.

18.3 *Mercurous Nitrate Test*—Prepare specimen as per Test Method B154.

18.4 *Ammonia Vapor Test*—Prepare specimen as per Test Method B858.

18.5 *Chemical Analysis*—Prepare specimens as per Test Method listed (see 19.1).

18.6 *Grain Size*—Prepare specimens per Test Methods E112.

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 performed in accordance with Test Methods E8/E8M. 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 E8/E8M, 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 E8/E8M may be used when a full section specimen cannot be tested.

19. Test Methods

19.1 *Chemical Analyses:*

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

Test	ASTM Designation
Chemical analysis	B170,[A] E53, E54, E62, E75, E76, E118, E478

[A] Reference to Specification B170 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 B170 annex will be eliminated.

19.1.2 Test methods to be followed for the determination of elements resulting from contractual or purchase order agreement shall be as agreed upon between the manufacturer or supplier and the purchaser.

19.2 *Other Tests:*

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

Test	ASTM Designation
Grain size	E112
Expansion (pin test)	B153
Mercurous nitrate	B154
Tension	E8/E8M
Nondestructive test	E243

19.2.2 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.

19.2.3 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 this 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).

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20. Significance of Numerical Limits

20.1 For the purpose 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 E29:

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. 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. C15630; 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

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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:*[7]

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:*[7]

MIL-STD-129 Marking for Shipment and Storage

S1.1.3 *Military Specification:*[4]

B900 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 B900.

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.

[7] Available from DLA Document Services, Building 4/D, 700 Robbins Ave., Philadelphia, PA 19111-5094, http://quicksearch.dla.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.

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TABLE X1.1 Densities

NOTE 1—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
C15630	0.320	8.87
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 (B111/B111M – 18) that may impact the use of this standard. (Approved Oct. 1, 2018.)

(1) Added Copper Alloy UNS No. C15630 to 1.1, Table 1, 6.2.2, Table 2, Table 3, Table 4, Section 26, and Table X1.1.

Committee B05 has identified the location of selected changes to this standard since the last issue (B111/B111M – 16) that may impact the use of this standard. (Approved March 1, 2018.)

(1) Added Copper Alloy UNS No. C28000 to 9.1.1.

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