



**Designation: B 111 – 98 (Reapproved 2004)**

# Standard Specification for Copper and Copper-Alloy Seamless Condenser Tubes and Ferrule Stock<sup>1</sup>

This standard is issued under the fixed designation B 111; 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<sup>2</sup> covers seamless tube and ferrule stock of copper and various copper alloys up to 3 1/8 in., inclusive, in diameter, for use in surface condensers, evaporators, and heat exchangers. Tubes for this application are normally made from the following coppers or copper alloys:<sup>3</sup>

Copper or Copper Alloy UNS No.	Previously Used Designation	Type of Metal
C10100	OFE	Oxygen-free electronic
C10200	OF <sup>A</sup>	Oxygen-free without residual deoxidants
C10300	...	Oxygen-free, extra low phosphorus
C10800	...	Oxygen-free, low phosphorus
C12000	DLP <sup>A</sup>	Phosphorized, low residual phosphorus
C12200	DHP <sup>A</sup>	Phosphorized, high residual phosphorus
C14200	DPA <sup>A</sup>	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
C71000	...	80-20 Copper-Nickel
C71500	...	70-30 Copper-Nickel
C71640	...	Copper-nickel-iron-manganese
C72200	...	...

<sup>A</sup> Designations listed in Classification B 224.

NOTE 1—A complete metric companion to Specification B 111 has been developed—B 111M; therefore, no metric equivalents are presented in this specification.

<sup>1</sup> 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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<sup>2</sup> For ASME Boiler and Pressure Vessel Code applications, see related Specification SB-111 in Section II of the Code.

<sup>3</sup> 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.

NOTE 2— **Warning**—Mercury is a definite health hazard in use and disposal. (See 12.1.)

1.2 The following safety hazards caveat pertains only to the test methods portion, Section 18, 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 of the issue in effect on date of material purchase form a part of this specification to the extent referenced herein:

### 2.2 ASTM Standards:<sup>4</sup>

- 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 and Copper Alloys
- B 170 Specification for Oxygen-Free Electrolytic Copper—Refinery Shapes
- B 224 Classification of Coppers
- E 8 Test Methods for Tension Testing of Metallic Materials
- E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
- E 53 Test Methods for Determination of Copper in Unalloyed Coppers by Gravimetry
- E 54 Test Methods for Chemical Analysis of Special Brasses and Bronzes<sup>5</sup>
- 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 112 Test Methods for Determining Average Grain Size
- E 243 Practice for Electromagnetic (Eddy Current) Examination of Copper and Copper-Alloy Tubes

<sup>4</sup> 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.

<sup>5</sup> Withdrawn.

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

- 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 (UNS)

**3. Terminology**

3.1 *Definitions:*

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

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

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

3.1.2.1 *tube, condenser, n*—See *tube, heat exchanger*.

3.1.2.2 *tube, ferrule, n*—a tube from which metal rings or collars (ferrules) are made for use in installing condenser tubes.

3.1.2.3 *tube, heat exchanger, n*—a tube manufactured to special requirements as to dimensional tolerances, finish, and temper for use in condensers and other heat exchangers.

3.2 *Description 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 Orders for material under this specification shall include the following information:

4.1.1 Quantity of each size (number of pieces and number of feet),

4.1.2 Material (Section 1),

4.1.3 Form (tube or ferrule stock),

4.1.4 Temper (Section 7),

4.1.5 Whether tension test is required (Section 7),

4.1.6 Whether a pressure test is to be used instead of the eddy current test (see 13.1),

4.1.7 Dimensions, the diameter, wall thickness, whether minimum or nominal wall, and length (see Section 14),

4.1.8 Whether cut ends of the tube are to be deburred (see 15.1),

4.1.9 If the product is to be subsequently welded (see Table 1 and Footnotes *G* and *H*).

4.1.10 Specification number and year of issue,

4.1.11 Certification, if required (see 22.1), and

4.1.12 Mill test report, if required (see 24.1).

4.2 When material is purchased for agencies of the U.S. government, this shall be specified in the contract or purchase order, and the material shall conform to the Supplementary Requirements as defined herein.

**TABLE 1 Chemical Requirements**

Copper or Copper Alloy UNS No.	Composition, %												
	Copper <sup>A</sup>	Tin	Aluminum	Nickel, incl Cobalt	Lead, max	Iron	Zinc	Manganese	Arsenic	Antimony	Phosphorus	Chromium	Other Named Elements
C10100	99.99 min <sup>B</sup>	...	...	...	0.0010	...	0.0001 max	...	...	...	0.0003 max	...	<sup>C</sup>
C10200 <sup>D</sup>	99.95 min	...	...	...	...	...	...	...	...	...	...	...	...
C10300	99.95 min <sup>E</sup>	...	...	...	...	...	...	...	...	...	0.001–0.005	...	...
C10800	99.95 min <sup>E</sup>	...	...	...	...	...	...	...	...	...	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	98.7 min	...	...	...	...	0.8–1.2	...	...	...	...	0.01–0.04	...	...
C23000	84.0–86.0	...	...	...	0.05	0.05 max	remainder	...	...	...	...	...	...
C28000	59.0–63.0	...	...	...	0.30	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	...	<sup>F,G</sup>
C61400	remainder	...	6.0–8.0	...	0.01	1.5–3.5	0.20 max	1.0 max	...	...	...	...	...
C68700	76.0–79.0	...	1.8–2.5	...	0.07	0.06 max	remainder	...	0.02–0.10	...	...	...	...
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 <sup>H</sup>	1.0–1.8	1.0 max <sup>H</sup>	1.0 max	...	...	<sup>H</sup>	...	<sup>H</sup>
C71000	remainder	...	...	19.0–23.0	0.05 <sup>H</sup>	0.50–1.0	1.0 max <sup>H</sup>	1.0 max	...	...	<sup>H</sup>	...	<sup>H</sup>
C71500	remainder	...	...	29.0–33.0	0.05 <sup>H</sup>	0.40–1.0	1.0 max <sup>H</sup>	1.0 max	...	...	<sup>H</sup>	...	<sup>H</sup>
C71640	remainder	...	...	29.0–32.0	0.05 <sup>H</sup>	1.7–2.3	1.0 max <sup>H</sup>	1.5–2.5	...	...	<sup>H</sup>	...	<sup>H</sup>
C72200	remainder	...	...	15.0–18.0	0.05 <sup>H</sup>	0.50–1.0	1.0 max <sup>H</sup>	1.0 max	...	...	<sup>H</sup>	0.30–0.70	<sup>H</sup>

<sup>A</sup> Copper (including silver).

<sup>B</sup> 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.

<sup>C</sup> 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.

<sup>D</sup> Oxygen in C10200 shall be 10 ppm max.

<sup>E</sup> Copper plus sum of named elements shall be 99.95 % min.

<sup>F</sup> Silicon shall be 0.10 % max.

<sup>G</sup> 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.

<sup>H</sup> 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.

## 5. Materials and Manufacture

5.1 The material shall be of such quality and purity that the finished product shall have the properties and characteristics prescribed in this specification, and shall be cold worked to the specified size.

## 6. Chemical Composition

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

6.2 These specification 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	99.5
C71000	99.5
C71500	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 %.

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 (O) temper unless otherwise specified on the purchase order.

7.2 Tubes of Copper Alloy UNS Nos. C71500 and C71640 shall be supplied in one of the following tempers as specified: (1) annealed (O) or (2) drawn, 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, end-annealed.

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 (O), (2) light-drawn (H55), (3) hard-drawn (H80), or (4) hard-drawn, end-annealed.

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

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

NOTE 3—Some tubes, when subjected to aggressive environments, may be subjected to stress-corrosion cracking failure because of the residual tensile stresses developed in straightening. 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.

## 9. Microscopical Examination

9.1 Samples of annealed-temper tubes selected for test shall be subjected to microscopical examination at a magnification of 75 diameters and shall show uniform and complete recrystallization. Materials other than 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, end-annealed, or drawn, stress-relieved tempers (HR50).

## 10. Expansion Test

10.1 Tube specimens selected for test shall withstand the expansion shown in Table 3 when expanded in accordance with Test Method B 153. The expanded tube shall show no cracking or rupture visible to the unaided eye.

NOTE 4—The term “unaided eye” as used herein permits the use of corrective spectacles necessary to obtain normal vision.

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 made on the annealed ends.

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

## 11. Flattening Test

11.1 Test specimens at least 18 in. in length in the annealed condition shall be flattened on different elements throughout the lengths remaining after specimens for the expansion and metallographic tests have been taken. Each element shall be slowly flattened by one stroke of a press. The term “flattened” shall be interpreted as follows: a micrometer caliper set at three times the wall thickness shall pass over the tube freely throughout the flattened part except at the points where the change in element of flattening takes place. The flattened elements shall not show cracking or rupture clearly visible to



TABLE 2 Tensile Requirements

Copper or Copper Alloy UNS No.	Temper Designation		Tensile Strength, min ksi <sup>A</sup>	Yield Strength, <sup>B</sup> min ksi <sup>A</sup>	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	O61	annealed	40	15	...
C70600	H55	light-drawn	45	35	...
C71000	O61	annealed	45	16	...
C71500	O61	annealed	52	18	...
C71500: Wall thicknesses up to 0.048 in., incl	HR50	drawn, stress-relieved	72	50	12
Wall thicknesses over 0.048 in.	HR50	drawn, stress-relieved	72	50	15
C71640	O61	annealed	63	25	...
C71640	HR50	drawn, stress relieved	81	58	...
C72200	O61	annealed	45	16	...
C72200	H55	light-drawn	50	30	...

<sup>A</sup> ksi = 1000 psi.

<sup>B</sup> At 0.5 % extension under load.

TABLE 3 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 C23000 C28000 C44300, C44400, C44500 C60800 C61300, C61400 C68700 C70400 C70600 C71000 C71500 C71640 C72200	30 20 15 20 20 20 30 30 30 30 30 30 30
H55	light-drawn	C10100, C10200, C10300, C10800, C12000, C12200 C14200 C19200 C70400 C70600 C72200	20 20 20 20 20
HR50	drawn, stress relieved	C71500 C71640	20 20
...	hard-drawn, end annealed	C10100, C10200, C10300, C10800, C12000, C12200, C14200	30

the unaided eye (Note 3). When tubes are specified in a temper other than annealed this test is required but shall be made on annealed specimens.

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

12. Mercurous Nitrate Test

12.1 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 The test specimens, cut 6 in. 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. The mercurous nitrate test is required only for Copper Alloy UNS Nos.