Designation: ~~B359/B359M – 12ε1~~ B359/B359M – 15

Standard Specification for Copper and Copper-Alloy Seamless Condenser and Heat Exchanger Tubes With Integral Fins[1]

This standard is issued under the fixed designation B359/B359M; 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.

~~ε[1] NOTE—Section S2.6 was editorially corrected in November 2013.~~

1. Scope*

1.1 This specification[2] establishes the requirements for seamless copper and copper alloy tubing on which the external or internal surface, or both, has been modified by a cold-forming process to produce an integral enhanced surface for improved heat transfer.

~~1.2 *Units*—The values stated in either in-pound units or SI units are to be regarded separately as the standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems could result in nonconformance with the specification.~~

1.2 The tubes are typically used in surface condensers, evaporators, and heat exchangers.

1.3 The product shall be produced of the following coppers or copper alloys, as specified in the ordering information.

~~Copper or Copper Alloy UNS No.~~ Copper or Copper Alloy UNS No.	~~Type of Metal~~ Type of Metal
C10100	Oxygen-free electronic
C10200	Oxygen-free without residual deoxidants
C10300	Oxygen-free, extra low phosphorus
C10800	Oxygen-free, low phosphorus
C12000	DLP Phosphorized, low residual phosphorus (See Note 1)
C12200	DHP, Phosphorized, high residual phosphorus (See Note 1)
C14200	DPA Phosphorized arsenical (See Note 1)
C19200	Phosphorized, 1 % iron
C23000	Red Brass
C44300	Admiralty Metal Types B,
C44400	C, and
C44550	D
C60800	Aluminum Bronze
C68700	Aluminum Brass Type B
C70400	95-5 Copper-Nickel
C70600	90-10 Copper-Nickel
C70620	90-10 Copper-Nickel (Modified for Welding)
C71000	80-20 Copper-Nickel Type A
C71500	70-30 Copper-Nickel
C71520	70-30 Copper-Nickel (Modified for Welding)
C72200	Copper-Nickel

NOTE 1—Designations listed in Classification B224.

[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-359 in Section II of that Code.

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

1.4 *Units*—The values stated in either in-pound units or SI units are to be regarded separately as the standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems could result in nonconformance with the specification.

1.5 Product produced in accordance with the Supplementary Requirements section for military applications shall be produced only to the inch-pound system of this specification.

1.6 The following safety hazard caveat pertains only to the test methods described in 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.* Some specific hazards statements are given in Sections 1, 12 and 18.

1.7 ~~Product (~~**Warning—**Mercury has been designated by many regulatory agencies as a hazardous material that can cause serious medical issues. Mercury, or its vapor, has been demonstrated to be hazardous to health and corrosive to materials. Caution should be taken when handling mercury and mercury containing products. See the applicable product Safety Data Sheet (SDS) for additional information. Users should be aware that selling mercury and/or mercury containing products into your state or country may be prohibited by law.~~produced in accordance with the Supplementary Requirements section for military applications shall be produced only to the inch-pound system of this specification.~~)~~

2. Referenced Documents

2.1 *ASTM Standards:*[3]

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
B601 Classification for Temper Designations for Copper and Copper Alloys—Wrought and Cast
B846 Terminology for Copper and Copper Alloys
B858 Test Method for Ammonia Vapor Test for Determining Susceptibility to Stress Corrosion Cracking in Copper Alloys
B900 Practice for Packaging of Copper and Copper Alloy Mill Products for U.S. Government Agencies
B968/B968M Test Method for Flattening of Copper and Copper-Alloy Pipe and Tube
D4727/D4727M Specification for Corrugated and Solid Fiberboard Sheet Stock (Container Grade) and Cut Shapes
E3 Guide for Preparation of Metallographic Specimens
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
E62 Test Methods for Chemical Analysis of Copper and Copper Alloys (Photometric Methods) (Withdrawn 2010)[4]
E112 Test Methods for Determining Average Grain Size
E118 Test Methods for Chemical Analysis of Copper-Chromium Alloys (Withdrawn 2010)[4]
E243 Practice for Electromagnetic (Eddy Current) Examination of Copper and Copper-Alloy Tubes
E255 Practice for Sampling Copper and Copper Alloys for the Determination of Chemical Composition
E478 Test Methods for Chemical Analysis of Copper Alloys
E2575 Test Method for Determination of Oxygen in Copper and Copper Alloys

3. General Requirements

3.1 Product described by this specification shall typically be furnished with unenhanced ends, but may be furnished with enhanced ends or stripped ends from which the O.D. enhancement has been removed by machining.

3.1.1 The enhanced sections of the tube in the as-fabricated temper are in the cold-worked condition produced by the enhancing operation.

3.1.2 The unenhanced sections of the tube shall be in the annealed or light drawn temper, and shall be suitable for rolling-in operations.

4. Terminology

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

4.2 *Definitions of Terms Specific to This Standard:*

4.2.1 *tube condenser, n*—see *tube, heat exchanger* in Terminology B846.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

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

5. Ordering Information

5.1 Include the following information when placing orders under this specification:

5.1.1 ASTM designation and year of issue,

5.1.2 Copper or Copper Alloy UNS No. designation (see ~~1.4~~1.3 and Section 7),

5.1.3 Temper (see Section 8),

5.1.4 Dimensions: diameter, wall thickness, length and location of unenhanced surfaces and total tube length. Configuration of enhanced surfaces shall be as agreed upon between the manufacturer and the purchaser. (See Figs. 1 and 2).

5.1.5 Whether the product is to be subsequently welded for UNS Alloy C72200, UNS Alloys C70620 and C71520 are welding grades of C70600 and C71500,

5.1.6 Quantity, and

5.1.7 If product is for the U.S. government.

5.2 The following options are available and shall be specified at the time of placing the order, when required:

5.2.1 When heat identification or traceability is required,

5.2.2 When tubes are for Boiler and Pressure Vessel code application, which should then be ordered according to ASME SB 359,

5.2.3 Flattening test (see 11.2),

5.2.4 Certification (see Section 22), when required,

5.2.5 Mill test report (see Section 23), when required, and

5.2.6 Stress relief annealing (see 9.4), when required.

5.3 In addition, when material is purchased for agencies of the U.S. government, it shall conform to the requirements specified in the Supplementary Requirements section, when specified in the contract or purchase order.

6. Materials and Manufacture

6.1 *Materials:*

6.1.1 The material of manufacture shall be of such quality and purity that the finished product shall have the properties and characteristics prescribed in this specification for the applicable alloy and temper.

6.2 *Manufacture:*

6.2.1 The seamless copper and copper alloy tubing shall have the internal or external surface, or both, modified by a cold forming process to produce an integral enhanced surface for improved heat transfer.

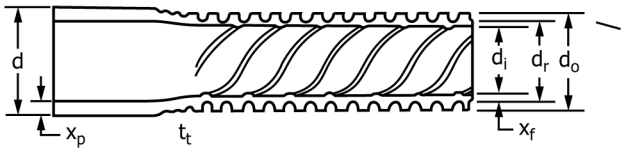
6.2.2 The cut ends of the tubes shall be deburred.

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

6.2.4 When heat identification is required, the purchaser shall specify the details desired in the purchase order or contract.

7. Chemical Composition

7.1 The tubes shall conform to the chemical requirements specified in Table 1 for copper or copper alloy specified in the ordering information.



d - Outside Diameter of Unenhanced Section

d_o - Outside Diameter over the Enhanced Section

d_r - Root diameter of the Enhanced Section

d_i - Inside Diameter of the Enhanced Section

x_p - Wall Thickness of the Unenhanced Section

x_f - Wall Thickness of the Enhanced Section

t_t - Transition Taper

NOTE 1—The outside diameter over the enhanced section will not normally exceed the outside diameter of the unenhanced section.

FIG. 1 Enhanced Tube Nomenclature

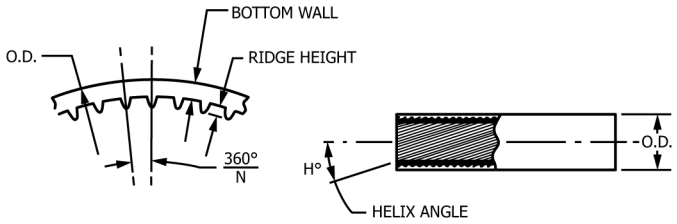


FIG. 2 Inside Enhanced Tube Nomenclature (Internal Groove Tube)

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

7.2.1 For alloys in which copper is specified as the remainder, copper may be taken as the difference between the sum of the results for all specified elements and 100 % for the particular alloy.

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

8. Temper

8.1 Tempers, as defined in Classification B601 and this document, are as follows:

8.1.1 The tube, after enhancing, shall be supplied, as specified, in the annealed (O61) or as-fabricated temper.

8.1.1.1 The enhanced sections of tubes in the as-fabricated temper are in the cold-worked condition produced by the fabricating operation.

8.1.1.2 The unenhanced sections of tubes in the as-fabricated temper are either in the temper of the tube prior to ~~enhancing, annealed (O61),~~enhancing (annealed (O61) or light drawn ~~(H55), and~~ (H55)) or when cold working of the unenhanced portions is performed as a part of the enhancing operations they shall be in the light drawn (H55) temper. In either case, the unenhanced surfaces shall be suitable for rolling-in operations.

8.1.1.3 Copper Alloy UNS Nos. C23000, C44300, C44400, C44500, C60800, and C68700, furnished in the as-fabricated temper, shall be stress relief annealed after enhancing and be capable of meeting the requirements of the stress-corrosion susceptibility requirement in Section 12. Stress-relief annealing of alloys not listed in this paragraph is not required unless specified by customer.

9. Grain Size of Annealed Temper

9.1 Samples of annealed-temper (O61) tubes selected for test shall be subjected to microscopical examination at a magnification of 75 diameters and shall show uniform and complete recrystallization.

9.2 Average grain size shall be within limits agreed upon between the manufacturer and purchaser.

9.3 The requirements of this section do not apply to product shipped in the as-fabricated temper.

9.4 Some annealed tubes, when subjected to aggressive environments, may be subject to stress-corrosion cracking failure because of the residual tensile stresses developed in straightening. For such applications, it is recommended that tubes of Copper Alloy UNS Nos. C23000, C44300, C44400, C44500, C60800, and C68700 be subjected to a stress relieving thermal treatment subsequent to straightening. When required, this must be specified on the purchase order or contract. Tolerance for roundness and length, and the condition for straightness, for tube so ordered, shall be to the requirements agreed upon between the manufacturer and purchaser.

10. Mechanical Property Requirements

10.1 *Tensile Property ~~Requirements:~~Requirements:*

10.1.1 Prior to the enhancing operation, the tube shall conform to the requirements for tensile properties prescribed in Table 2.

TABLE 1 Chemical Composition

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,B]	0.0002 max	...	0.0010 max	0.0005	0.0010 max	0.0001 max	0.00005 max	0.0005 max	0.0004 max	0.0003 max	...	Te 0.0002
C10200	99.95 min[C,D,E]	...	...	...	...	...	...	...	...	...	...	...	...
C10300	99.95 min[C,F,G]	...	...	...	...	...	...	...	...	...	0.001–0.005	...	...
C10800	99.95 min[C,F,G]	...	...	...	...	...	...	...	...	...	0.005–0.012	...	...
C12000	99.90 min[C]	...	...	...	...	...	...	...	...	...	0.004–0.012	...	...
C12200	99.9 min[C]	...	...	...	...	...	...	...	...		0.015–0.040	...	
C14200	99.4 min[C]	...	...	...	...	...	...	...	0.15–0.50	...	0.015–0.040	...	...
C19200	98.5 min[H]	...	...	...	...	0.8–1.2	0.20 max	...	...	...	0.01–0.04	...	...
C23000	84.0–86.0[H]	...	...	...	0.05	0.05 max	remainder	...	...	...	...	...	...
C44300	70.0–73.0[I]	0.9–1.2	...	...	0.07	0.06 max	remainder	...	0.02–0.06	...	...	...	...
C44400	70.0–73.0[I]	0.9–1.2	...	...	0.07	0.06 max	remainder	...	...	0.02–0.10	...	...	...
C44500	70.0–73.0[I]	0.9–1.2	...	...	0.07	0.06 max	remainder	...	...	...	0.02–0.10	...	...
C60800	remainder[C,J]	...	5.0–6.5	...	0.10	0.10 max	...	...	0.02–0.35	...	...	...	...
C68700	76.0–79.0[C,J]	...	1.8–2.5	...	0.07	0.06 max	remainder	...	0.02–0.06	...	...	...	...
C70400	remainder[C,J]	...	...	4.8–6.2	0.05	1.3–1.7	1.0 max	0.30–0.8	...	...	...	...	...
C70600	remainder[C,J]	...	...	9.0–11.0	0.05	1.0–1.8	1.0 max	1.0 max	...	...	...	...	...
C70620	86.5 min[C,J]	...	...	9.0–11.0	0.02	1.0–1.8	0.5 max	1.0 max	...	...	0.02 max	...	0.05 C max 0.02 S max
C71000	remainder[C,J,K]	...	...	19.0–23.0	0.05	1.0 max	1.0 max	1.0 max	...	...		...	...
C71500	remainder[C,J]	...	...	29.0–33.0	0.05	0.40–1.0	1.0 max	1.0 max	...	...	...	...	...
C71520	65.0 min[G,J]	...	...	29.0–33.0	0.02	0.40–1.0	0.50 max	1.0 max	...	...	0.02 max	...	0.05 C max 0.02 S max
C72200	remainder[C,H,K]	...	...	15.0–18.0	0.05	0.50–1.0	1.0 max	1.0 max	...	...	...	0.30–0.70	0.03 Si 0.03 Ti

TABLE 1 Chemical Composition

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,B]	0.0002 max	...	0.0010 max	0.0005	0.0010 max	0.0001 max	0.00005 max	0.0005 max	0.0004 max	0.0003 max	...	Te 0.0002
C10200	99.95 min[C,D,E]	...	...	...	...	...	...	...	...	...	...	...	...
C10300	99.95 min[C,F,G]	...	...	...	...	...	...	...	...	...	0.001–0.005	...	...
C10800	99.95 min[C,F,G]	...	...	...	...	...	...	...	...	...	0.005–0.012	...	...
C12000	99.90 min[C]	...	...	...	...	...	...	...	...	...	0.004–0.012	...	...
C12200	99.9 min[C]	...	...	...	...	...	...	...	...		0.015–0.040	...	
C14200	99.4 min[C]	...	...	...	...	...	...	...	0.15–0.50	...	0.015–0.040	...	...
C19200	98.5 min[H]	...	...	...	...	0.8–1.2	0.20 max	...	...	...	0.01–0.04	...	...
C23000	84.0–86.0[H]	...	...	...	0.05	0.05 max	remainder	...	...	...	...	...	...
C44300	70.0–73.0[I]	0.9–1.2	...	...	0.07	0.06 max	remainder	...	0.02–0.06	...	...	...	...
C44400	70.0–73.0[I]	0.9–1.2	...	...	0.07	0.06 max	remainder	...	...	0.02–0.10	...	...	...
C44500	70.0–73.0[I]	0.9–1.2	...	...	0.07	0.06 max	remainder	...	...	...	0.02–0.10	...	...
C60800	remainder[C,J]	...	5.0–6.5	...	0.10	0.10 max	...	...	0.02–0.35	...	...	...	...
C68700	76.0–79.0[C,J]	...	1.8–2.5	...	0.07	0.06 max	remainder	...	0.02–0.06	...	...	...	...
C70400	remainder[C,J]	...	...	4.8–6.2	0.05	1.3–1.7	1.0 max	0.30–0.8	...	...	...	...	...
C70600	remainder[C,J]	...	...	9.0–11.0	0.05	1.0–1.8	1.0 max	1.0 max	...	...	...	...	...
C70620	86.5 min[C,J]	...	...	9.0–11.0	0.02	1.0–1.8	0.5 max	1.0 max	...	...	0.02 max	...	0.05 C max 0.02 S max
C71000	remainder[C,J,K]	...	...	19.0–23.0	0.05	1.0 max	1.0 max	1.0 max	...	...		...	...
C71500	remainder[C,J]	...	...	29.0–33.0	0.05	0.40–1.0	1.0 max	1.0 max	...	...	...	...	...
C71520	65.0 min[G,J]	...	...	29.0–33.0	0.02	0.40–1.0	0.50 max	1.0 max	...	...	0.02 max	...	0.05 C max 0.02 S max
C72200	remainder[C,H,K]	...	...	15.0–18.0	0.05	0.50–1.0	1.0 max	1.0 max	...	...	...	0.30–0.70	0.03 Si 0.03 Ti

[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, zinc, phosphorus, selenium, tellurium, manganese, cadmium, and oxygen present in the sample.
[B] Other impurity maximums for C10100 shall be: bismuth and cadmium 0.0001 each, oxygen 0.0005, selenium 0.0003, silver 0.0025, and sulfur 0.0015.
[C] Copper (including silver).
[D] Oxygen in C10200 shall be 0.0010 max.
[E] Cu is determined by the difference in the impurity total and 100 %.
[F] Copper plus sum of named elements shall be 99.95 % min.
[G] Includes P.
[H] Cu + Sum of Named Elements, 99.8 % min.
[I] Cu + Sum of Named Elements, 99.6 % min.
[J] Cu + Sum of Named Elements, 99.5 % min.

[K] When the product is for subsequent welding applications, and so specified in the contract or purchase order, zinc shall be 0.50 % max, lead 0.02 % max, phosphorus 0.02 % max, sulfur 0.02 % max, and carbon 0.05 % max.

TABLE 2 Tensile Requirements

Copper or Copper Alloy UNS No.	Temper Designation		Tensile Strength, min	Yield Strength,[A] min
	Standard	Former	ksi[B] [MPa]	ksi[B] [MPa]
C10100, C10200, C10300, C10800, C12000, C12200, C14200	O61	annealed	30 [205]	9 [62][C]
C10100, C10200, C10300, C10800, C12000, C12200, C14200	H55	light-drawn	36 [250]	30 [205]
C19200	O61	annealed	38 [260]	12 [85]
C23000	O61	annealed	40 [275]	12 [85]
C44300, C44400, C44500	O61	annealed	45 [310]	15 [105]
C60800	O61	annealed	50 [345]	19 [130]
C68700	O61	annealed	50 [345]	18 [125]
C70400	O61	annealed	38 [260]	12 [85]
C70600	O61	annealed	40 [275]	15 [105]
C70620	O61	annealed	40 [275]	15 [105]
C71000	O61	annealed	45 [310]	16 [110]
C71500	O61	annealed	52 [360]	18 [125]
C71520	O61	annealed	52 [360]	18 [125]
C72200	O61	annealed	45 [310]	16 [110]

[A] At 0.5 % extension under load.
[B] ksi = 1000 psi.
[C] Light straightening operation is permitted.

10.1.2 Alternatively, for those enhancing operations that include cold working of the unenhanced portions of the tube integral to the process, the unenhanced portions shall conform to the H55 as prescribed in Table 2 for the UNS alloys identified.

11. Performance Requirements

11.1 *Expansion Test*—The unenhanced sections of all tubes selected for test shall conform to the requirements prescribed in Table 3 when tested in accordance with Test Method B153. The expanded tube shall show no cracking or rupture visible to the

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~~	~~C10100, C10200, C10300, C10800, C12000, C12200, C14200~~	~~30~~
~~H55~~	~~light-drawn~~	~~C10100, C10200, C10300, C10800, C12000, C12200, C14200~~	~~20~~
~~O61~~	~~annealed~~	~~C19200~~	~~30~~
~~O61~~	~~annealed~~	~~C23000~~	~~20~~
~~O61~~	~~annealed~~	~~C44300, C44400, C44500~~	~~20~~
~~O61~~	~~annealed~~	~~C60800~~	~~20~~
~~O61~~	~~annealed~~	~~C68700~~	~~20~~
~~O61~~	~~annealed~~	~~C70400~~	~~30~~
~~O61~~	~~annealed~~	~~C70600, C70620~~	~~30~~
~~O61~~	~~annealed~~	~~C71000~~	~~30~~
~~O61~~	~~annealed~~	~~C71500, C71520~~	~~30~~
~~O61~~	~~annealed~~	~~C72200~~	~~30~~

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	C10100, C10200, C10300, C10800, C12000, C12200, C14200	30
H55	light-drawn	C10100, C10200, C10300, C10800, C12000, C12200, C14200	20
O61	annealed	C19200	30
O61	annealed	C23000	20
O61	annealed	C44300, C44400, C44500	20
O61	annealed	C60800	20
O61	annealed	C68700	20
O61	annealed	C70400	30
O61	annealed	C70600, C70620	30
O61	annealed	C71000	30
O61	annealed	C71500, C71520	30
O61	annealed	C72200	30