Designation: B 359 – 98

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 B 359; 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] describes 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. The tubes are used in surface condensers, evaporators, and heat exchangers and are normally made from the following copper or copper alloys:

Copper or Copper Alloy UNS No.	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
C12200	DHP, Phosphorized, high residual phosphorus
C14200	DPA Phosphorized arsenical
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
C71000	80-20 Copper-Nickel Type A
C71500	70-30 Copper-Nickel
C72200	Copper-Nickel

NOTE 1—Refer to Practice E 527 for explanation of Unified Numbering System (UNS).

1.2 The following safety hazard caveat pertains only to the test methods described in this specification.

1.2.1 *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.*

NOTE 2—A complete metric companion, B 359M, has been developed; therefore, no metric equivalents are presented.

2. Referenced Documents

2.1 *ASTM Standards:*

B 153 Test Method for Expansion (Pin Test) of Copper and Copper-Alloy Pipe and Tubing[3]

B 154 Test Method for Mercurous Nitrate Test for Copper and Copper Alloys[3]

B 170 Specification for Oxygen-Free Electrolytic Copper—Refinery Shapes[3]

B 359M Specification for Copper and Copper-Alloy Seamless Condenser and Heat Exchanger Tubes with Integral Fins [Metric][3]

E 3 Methods of Preparation of Metallographic Specimens[4]

E 8 Test Methods for Tension Testing of Metallic Materials[4]

E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications[5]

E 53 Methods for Chemical Analysis of Copper[6]

E 62 Methods for Chemical Analysis of Copper and Copper Alloys (Photometric Methods)[6]

E 112 Test Methods for Determining Average Grain Size[4]

E 118 Test Methods for Chemical Analysis of Copper-Chromium Alloys[6]

E 243 Practice for Electromagnetic (Eddy-Current) Examination of Copper and Copper-Alloy Tubes[7]

E 255 Practice for Sampling Copper and Copper Alloys for Determination of Chemical Composition[6]

E 478 Test Methods for Chemical Analysis of Copper Alloys[8]

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

3. Terminology

3.1 *Definitions:*

3.1.1 *flattening*—this term shall be interpreted as that condition which allows a micrometer caliper, set at three times the wall thickness, to pass over the tube freely throughout the

[1] This specification is under the jurisdiction of ASTM Committee B-5 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.

[3] *Annual Book of ASTM Standards*, Vol 02.01.

[4] *Annual Book of ASTM Standards*, Vol 03.01.

[5] *Annual Book of ASTM Standards*, Vol 14.02.

[6] *Annual Book of ASTM Standards*, Vol 03.05.

[7] *Annual Book of ASTM Standards*, Vol 03.03.

[8] *Annual Book of ASTM Standards*, Vol 03.06.

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

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

flattened part, except at the points where the change in element of flattening takes place.

3.1.2 *lengths*—straight pieces of product.

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

3.1.3 *tube, seamless*—a tube produced with a continuous periphery in all stages of operation.

3.1.3.1 *tube condenser*—see *tube, heat exchanger.*

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

3.1.3.3 *tube, heat exchangers with integral enhanced surface*—a tube having an external or internal surface, or both, modified by a cold forming operation, to produce an enhanced surface for improved heat transfer. The enhancement may take the form of longitudinal or helical fins or ridges, or both, as well as modifications thereto.

3.1.4 *unaided eye*—corrective spectacles necessary to obtain normal vision may be used.

4. Ordering Information

4.1 Purchase orders for tubes described in this specification should include the following, as required, to describe the tubes adequately.

4.1.1 ASTM designation and year of issue,

4.1.2 Alloy,

4.1.3 Temper,

4.1.4 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. (Refer to Figs. 1-3).

4.1.5 Whether the product is to be subsequently welded,

4.1.6 Quantity,

4.1.7 Certification, when required,

4.1.8 Mill test report, when required,

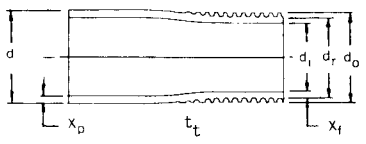
4.1.9 When heat identification or traceability is required, and

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

5. General Requirements

5.1 Tubes described by this specification shall normally 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.

5.1.1 The enhanced sections of the tube in the as-fabricated temper are in the cold-worked condition produced by the enhancing operation. The unenhanced sections of the tube shall be in the annealed or light drawn temper, and shall be suitable for rolling-in operations.



d - Outside Diameter of Unenhanced Section

d_o- Outside Diameter of the Enhanced Section

d_r- Root Diameter of the Enhanced Section

x_p- Wall Thickness of the Unenhanced Section

x_f- Wall Thickness of the Unenhanced Section

t_t- Transition Taper

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

FIG. 1 Outside Diameter Enhanced Tube Nomenclature

6. Materials and Manufacture

6.1 The material shall be of such quality and purity that the finished products shall conform to the requirements prescribed in this specification and shall be cold-worked to the specified size. To comply with this specification, the enhanced and unenhanced material must be homogeneous.

6.2 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.

6.3 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.

7.2 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.

7.2.1 *Copper Alloy C19200*—Copper may be taken as the difference between the sum of results for all specified elements and 100 %. When all elements specified, including copper, are determined, their sum shall be 99.8 % minimum.

7.2.2 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.

7.2.2.1 When analyzed, copper plus the sum of results for specified elements shall be as shown in the following table.

Copper Alloy UNS No.	Copper Plus Named Elements, % min
C60800	99.5
C70400	99.5
C70600	99.5
C71000	99.5
C71500	99.5
C72200	99.8

7.2.3 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 %.

7.2.3.1 When all specified elements are determined the sum of results plus copper shall be as follows:

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

8. Temper

8.1 The tube after enhancing shall be supplied, as specified,

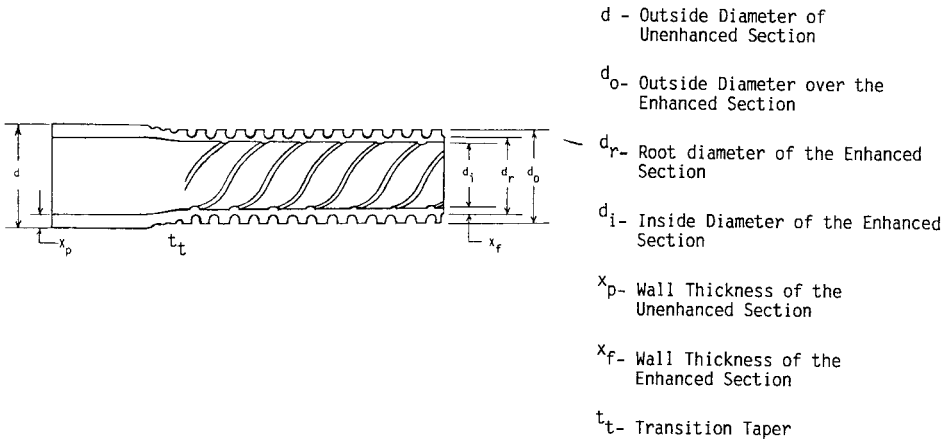


FIG. 2 Outside Diameter and Inside Diameter Enhanced Tube Nomenclature

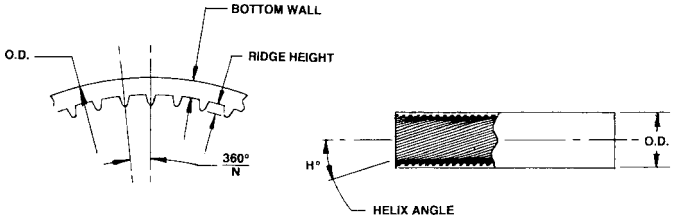


FIG. 3 Inside Diameter Enhanced Tube Nomenclature

in the annealed or as-fabricated temper.

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

8.1.2 The unenhanced sections of tubes in the as-fabricated temper are in the temper of the tube prior to enhancing, annealed or light drawn, and suitable for rolling-in operations.

8.1.3 Copper alloys C23000, C44300, C44400, C44500, C60800, and C68700, furnished in the as-fabricated temper, must be stress relief annealed after enhancing and be capable of meeting the requirements of the mercurous nitrate test in Section 12. Stress relief annealing of the copper and other copper alloys described by this specification is not required.

8.1.3.1 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 alloys 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.

8.1.4 The enhanced sections of tubes in the annealed temper shall show complete recrystallization when examined in the cross-section of the tube at a magnification of 75 diameters. Average grain size shall be within the limits agreed upon between the manufacturer and purchaser, when measured in the wall of the tube outside of the enhanced area.

9. Tensile Properties

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

10. Expansion Test

10.1 The unenhanced sections of all tubes selected for test shall conform to the requirements prescribed in Table 3 when tested in accordance with B 153. The expanded tube shall show no cracking or rupture visible to the unaided eye.

11. Flattening Test

11.1 The unenhanced lengths of tube selected for tests shall be flattened on different elements and a flattened element shall show no cracking or rupture visible to the unaided eye. (Corrective spectacles necessary to obtain normal vision may be used.)

12. Mercurous Nitrate Test

12.1 Each specimen shall withstand an immersion in the mercurous nitrate solution as prescribed in Test Method B 154 without cracking. The enhanced specimens shall include the finished tube ends.

12.2 This test is required only for copper alloys C23000, C44300, C44400, C44500, C60800, and C68700.

13. Non-destructive Testing

13.1 Each tube shall be subjected to a non-destructive test. Tubes shall normally be tested in the as-fabricated temper but, at the option of the manufacturer, may be tested in the annealed temper. Unless otherwise specified, the manufacturer shall have the option of testing the tubes by one of the following test methods.

13.1.1 *Eddy-Current Test*—The tubes shall be passed through an eddy-current testing unit adjusted per the requirements of 19.3.3 to provide information on the suitability of the tube for the intended application.

13.1.1.1 Tubes causing irrelevant signals because of moisture, soil, and like effects may be reconditioned and retested. Such tubes shall be considered to conform, should they not cause output signals beyond the acceptable limits.

13.1.1.2 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.

13.1.1.3 Unless otherwise agreed, tubes meeting the requirements of either test shall be considered to conform if the tube dimensions are within the prescribed limits.

TABLE 1 Chemical Requirements

Copper or Copper Alloy UNS No.	Composition, %												
	Copper[A]	Tin	Alumi-num	Nickel, incl Cobalt	Lead, max	Iron	Zinc	Manganese	Arsenic	Antimony	Phosphorus	Chromium	Other Named Ele-ments
C10100	99.99 min[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	. . .	[C]
C10200[D]	99.95 min	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
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	98.7 min	. . .	. . .	. . .	. . .	0.8–1.2	. . .	. . .	. . .	. . .	0.01–0.04	. . .	. . .
C23000	84.0–86.0	. . .	. . .	. . .	0.05	0.05 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	. . .	. . .	. . .	. . .
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[F]	1.0 max	. . .	. . .	[F]	. . .	[F]
C71000	remainder	. . .	. . .	19.0–23.0	0.05	0.50–1.0	1.0 max[F]	1.0 max	. . .	. . .	[F]	. . .	[F]
C71500	remainder	. . .	. . .	29.0–33.0	0.05	0.40–1.0	1.0 max[F]	1.0 max	. . .	. . .	[F]	. . .	[F]
C72200	remainder	. . .	. . .	15.0–18.0	0.05	0.50–1.0	1.0 max[F]	1.0 max	. . .	. . .	[F]	0.30–0.70	[F]

[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] Other impurity maximums for C10100 shall be: bismuth, cadmium and mercury 0.0001 each, oxygen 0.0005, selenium 0.0003, silver 0.0025, sulfur 0.0015, and tellurium 0.0002.
[D] Oxygen in C10200 shall be 0.0010 max.
[E] Copper plus sum of named elements shall be 99.95 % min.
[F] 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, and sulfur 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]	ksi[B]
C10100, C10200, C10300, C10800, C12000, C12200, C14200	O61	annealed	30	9[C]
C10100, C10200, C10300, C10800, C12000, C12200, C14200	H55	light-drawn	36	30
C19200	O61	annealed	38	12
C23000	O61	annealed	40	12
C44300, C44400, C44500	O61	annealed	45	15
C60800	O61	annealed	50	19
C68700	O61	annealed	50	18
C70400	O61	annealed	38	12
C70600	O61	annealed	40	15
C71000	O61	annealed	45	16
C71500	O61	annealed	52	18
C72200	O61	annealed	45	16

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

13.1.2 *Hydrostatic Test*— Each tube, without showing evidence of leakage, shall withstand an internal hydrostatic pressure sufficient to subject the material in the unenhanced region of the tube to a fiber stress of 7000 psi, as determined by the following equation for thin hollow cylinders under tension.

$$P = 2St/(D - 0.8t) \quad (1)$$

where
P = hydrostatic pressure, Psig,
t = thickness of tube wall, in.,
D = outside diameter of tube, in., and
S = allowable fiber stress of the material, psi.

The tube need not be tested at a hydrostatic pressure over 1000