



Designation: B359/B359M – 12

Standard Specification for Copper and Copper-Alloy Seamless Condenser and Heat Exchanger Tubes With Integral Fins¹

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.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This specification² 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.

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

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

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 (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.

1.5 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.*

1.6 Product 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

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 April 1, 2012. Published May 2012. Originally approved in 1960. Last previous edition approved in 2002 as B359/B359M – 02 (2006). DOI: 10.1520/B0359_B0359M-12.

² For ASME Boiler and Pressure Vessel Code applications see related Specification SB-359 in Section II of that Code.

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.

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

- 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

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.

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 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.

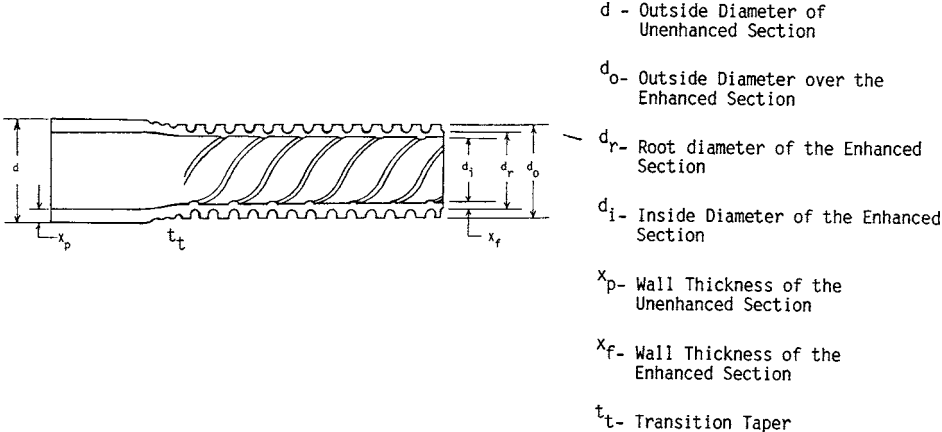
- 5.2 The following options are available and shall be specified at the time of placing the order, when required:
 - 5.2.1 When heat identification or traceability is required,
 - 5.2.2 When tubes are for Boiler and Pressure Vessel code application, which should then be ordered according to ASME SB 359,
 - 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.

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



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

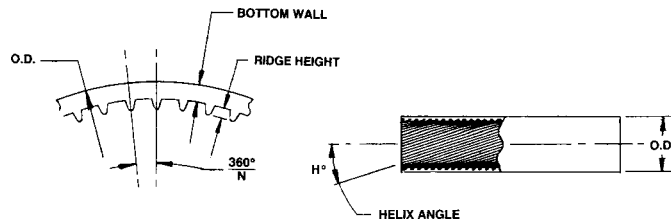


FIG. 2 Inside Enhanced Tube Nomenclature (Internal Groove Tube)

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.

TABLE 1 Chemical Composition

Table with 14 columns: Copper or Copper Alloy UNS No., Copper, Tin, Aluminum, Nickel, incl Cobalt, Lead, max, Iron, Zinc, Manganese, Arsenic, Antimony, Phosphorus, Chromium, Other Named Elements. Rows include C10100, C10200, C10300, C10800, C12000, C12200, C14200, C19200, C23000, C44300, C44400, C44500, C60800, C68700, C70400, C70600, C70620, C71000, C71500, C71520, C72200.

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.

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 in the temper of the tube prior to enhancing, annealed (O61), or light drawn (H55), and 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:

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

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 unaided eye.

11.2 Flattening Test:

11.2.1 When specified in the contract or purchase order, the flattening test described in the test method **B968/B968M** shall be performed.

11.2.1.1 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.

12. Other Requirements

12.1 Mercurous Nitrate Test or Ammonia Vapor Test:

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
	H55	light-drawn	36 [250]	30 [205]
C10100, C10200, C10300, C10800, C12000, C12200, C14200 C19200 C23000 C44300, C44400, C44500 C60800 C68700 C70400 C70600 C70620 C71000 C71500 C71520 C72200	O61	annealed	38 [260]	12 [85]
	O61	annealed	40 [275]	12 [85]
	O61	annealed	45 [310]	15 [105]
	O61	annealed	50 [345]	19 [130]
	O61	annealed	50 [345]	18 [125]
	O61	annealed	38 [260]	12 [85]
	O61	annealed	40 [275]	15 [105]
	O61	annealed	40 [275]	15 [105]
	O61	annealed	45 [310]	16 [110]
	O61	annealed	52 [360]	18 [125]
	O61	annealed	52 [360]	18 [125]
	O61	annealed	45 [310]	16 [110]

^A At 0.5 % extension under load.

^B ksi = 1000 psi.

^C Light straightening operation is permitted.



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

12.1.1 The mercurous nitrate or ammonia vapor test is required only for Copper Alloys UNS Nos. C23000, C44300, C44400, C44500, C60800, and C68700. (**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.)

12.1.2 The test specimens, cut 6 in. [150 mm] in length from the enhanced section shall withstand, without cracking, an immersion in the standard mercurous nitrate solution in Test Method B154 or immersion in the ammonia vapor solution as defined in Test Method B858.

12.1.3 Unless otherwise agreed upon between the manufacturer, or supplier, and the purchaser, the manufacturer shall have the option of using either the mercurous nitrate test or the ammonia vapor test. If agreement cannot be reached, the mercurous nitrate test standard shall be utilized.

12.1.4 If the ammonia vapor test is selected, the appropriate risk level pH value for the test solution shall be agreed upon by the manufacturer and purchaser, or alternately, if the purchaser defers to the manufacturer’s expertise for the selection of the test pH value, the minimum value selected shall be 9.8.

12.2 Non-Destructive Testing:

12.2.1 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:

12.2.1.1 Non-Destructive Examination for Defects:

(1) The tubes shall be passed through an eddy-current testing unit adjusted per the requirements of 18.3.3 to provide information on the suitability of the tube for the intended application.

(2) 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.

(3) Tubes causing irrelevant signals because of visible and identifiable handling marks may be retested by the hydrostatic test prescribed in 12.2.1.2 or the pneumatic test prescribed in 12.2.1.3.

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

12.2.1.2 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 [48 MPa], as determined by the following equation for thin hollow cylinders under tension:

$$P = \frac{2St}{(D - 0.8t)} \tag{1}$$

where:

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

The tube need not be tested at a hydrostatic pressure over 1000 psi [6.9 MPa] unless so specified.

12.2.1.3 Pneumatic Test—Each tube, after enhancing, shall withstand a minimum internal air pressure of 250 psig [1.7 MPa] for 5 s and any evidence of leakage shall be cause for rejection. The test method used shall permit easy visual detection of any leakage, such as having the tube under water, or by the pressure differential method.

13. Dimensions, Mass, and Permissible Variations

13.1 Tube Diameter:

13.1.1 The outside diameter of the unenhanced sections shall not vary by more than the amount shown in Table 4 for the appropriate dimensional system, as measured by “go” and “no go” ring gages. The diameter over the enhanced sections shall not exceed the diameter of the plain sections involved, as determined by a “go” ring gage, unless otherwise specified.

TABLE 4 Diameter Tolerances

Specified Diameter, in. [mm]	Tolerance, in. [mm]
0.500 [12.0] and under	±0.002 [0.050]
Over 0.500–0.740 [12.0–18.0], incl	±0.0025 [0.063]
Over 0.740–1.000 [18.0–25.0], incl	±0.003 [0.076]
Over 1.000	As agreed upon

13.2 *Wall Thickness*—No tube shall be less than the minimum thickness specified in the plain sections or in the enhanced sections.

13.3 *Length:*

13.3.1 The length of the tubes shall not be less than that specified when measured at a temperature of 68°F [20°C], but may exceed the specified value by the amounts shown in **Table 5**, for the appropriate dimensional system.

13.3.2 The length of the unenhanced end(s), as measured from the tube end to the first fin disk impression, shall not be less than that specified, but may exceed the specified value by ½ in. [13 mm].

13.4 *Squareness of Cut*—The departure from squareness of the end of any tube shall not exceed the tolerance stated in **Table 6**, for the appropriate dimensional system.

14. **Workmanship, Finish, and Appearance**

14.1 Roundness, straightness, uniformity of wall thickness, and condition of inner and outer surfaces 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.

14.2 Annealed-temper (O61) or stress-relieved tubes shall be clean and smooth, but may have a superficial, dull iridescent film on both the inside and outside surface. Tubes in the as-fabricated temper may have a superficial film of finning lubricant on the surfaces.

15. **Sampling**

15.1 The lot size, portion size, and selection of sample pieces shall be as follows:

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

15.1.2 *Portion Size*—Sections from two individual lengths of finished product.

15.1.2.1 Samples taken for purposes of test shall be selected in a manner that will correctly represent the material furnished and avoid needless destruction of finished material when samples representative of the material are available from other sources.

15.2 *Chemical Composition:*

15.2.1 Samples for determining composition shall be taken in accordance with Practice **E255**. The minimum weight of the composite sample shall be 150 g.

15.2.2 Instead of sampling in accordance with Practice **E255**, the manufacturer shall have the option of sampling at the time castings are poured or sampling the semi-finished product. When samples are taken during the course of manufacture,

TABLE 5 Length Tolerances

Specified Length, ft [mm]	Tolerance, all Plus, in. [mm]
Up to 20 [6000], incl	1/8 [3.2]
Over 20–30 [6000-10 000], incl	3/32 [4.0]
Over 30–60 [10 000-18 000], incl	1/4 [6.4]

TABLE 6 Squareness of Cut

Specified Outside Diameter, in. [mm]	Tolerance, in. [mm]
Up to 5/8 [16.0], incl	0.010 [0.25]
Over 5/8 [16.0]	0.016 in./in. [0.016 mm/mm] of diameter

sampling of the finished product is not required and the minimum number of samples to be taken shall be as follows:

15.2.2.1 When samples are taken at the time castings are poured, one sample shall be taken for each group of castings poured simultaneously from the same source of molten metal.

15.2.2.2 When samples are taken from the semi-finished product, one 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. **Number of Tests and Retest**

16.1 *Tests:*

16.1.1 *Chemical Analysis*—Chemical composition shall be determined as the arithmetic mean of at least two replicate determinations of each specified element.

16.1.2 *Grain Size*—For annealed temper only, two tubes shall be selected from each lot and each tube shall be tested to verify the requirements of Section 9.

16.1.3 *Tensile Property Requirements*—Two tubes shall be selected from each lot prior to enhancement and each tube shall be tested to verify the requirements of Section 10.

16.1.4 *Expansion Test*—Two tubes shall be selected from each lot prior to enhancement and each tube shall be tested to verify the requirements in 11.1.

16.1.5 *Flattening Test*—One tube shall be selected from each lot prior to enhancement and each tube shall be tested to verify the requirements of 11.2.

16.1.6 *Mercurous Nitrate Test or Ammonia Vapor Test*—Two tubes shall be selected from each lot after enhancement and stress relief anneal. Each tube shall be tested to verify the requirements of 12.1.2.

16.2 *Retest:*

16.2.1 One retest shall be permitted for each requirement under the same conditions stated for the original test.

16.2.2 Should the result of a retest fail to conform with the requirements of the product specification, the material shall be rejected.

17. **Specimen Preparation**

17.1 *Chemical Analysis:*

17.1.1 Sample preparation shall be in accordance with Practice **E255**.

17.1.2 Preparation of the analytical test specimen shall be the responsibility of the reporting laboratory.

17.2 *Grain Size:*

17.2.1 Specimens for the microscopic examination shall be prepared in accordance with Test Methods **E3**.

17.2.2 The surface of the specimen shall approximate a radial longitudinal section of the tube.

17.3 *Expansion Test Specimen:*