Designation: B 543 – 96 (Reapproved 2003)

Standard Specification for Welded Copper and Copper-Alloy Heat Exchanger Tube[1]

This standard is issued under the fixed designation B 543; 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 covers welded tube of copper and various copper alloys up to 3⅛ in., inclusive, in diameter, for use in surface condensers, evaporators, heat exchangers, and general engineering applications. Tubes for this application are normally made of the following coppers or copper alloys:[2]

Copper or Copper Alloy UNS No.[2]	Previously Used Designation	Type of Metal
C10800	...	oxygen-free, low phosphorus
C12200	DHP[A]	phosphorized, high residual phos phorus
C19400	...	copper-iron alloy
C23000	...	red brass
C44300	...	arsenical admiralty
C44400	...	antimonial admiralty
C44500	...	phosphorized admiralty
C68700	...	arsenical aluminum brass
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	...	...

[A] Designation listed in Classification B 224.

1.2 *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.* (**Warning**—Mercury is a definite health hazard in use and disposal. (See 14.1.))

NOTE 1—A complete metric companion to Specification B 543 has been developed—B 543M; therefore, no metric equivalents are presented in this specification.

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:* [3]

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 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 Determination of Copper in Unalloyed Copper by Gravimetry

E 54 Test Methods for Chemical Analysis of Special Brasses and Bronzes[4]

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

E 478 Test Methods for Chemical Analysis of Copper Alloys

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

E 527 Practice for Numbering Metals and Alloys (UNS)

3. Terminology

3.1 *Description of Term Specific to This Standard:*

3.1.1 *capable of*—as used in this specification, the test need not be performed by the producer of the material. However,

[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] New designation established in accordance with Practice E 527. In the new UNS system, the designations for copper alloys are simply expansions of the present standard designations by a prefix "C" and a suffix "00."

[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] Withdrawn.

should subsequent testing by the purchaser establish that the material does not meet these requirements, the material shall be subject to rejection.

4. Types of Welded Tube

4.1 *Forge-Welded Tube* manufactured as described in 6.2.1, 6.2.1.1, and 6.2.1.2.

4.1.1 *As-Welded Tube*—Forge-welded tube with internal and external flash removed and no further refinement of grain structure.

4.1.2 *Welded and Annealed Tube*—Forge-welded tube with internal and external flash removed, that has been annealed to produce a uniform grain size appropriate to the specified annealed temper.

4.1.3 *Welded and Cold-Reduced Tube*—Forge-welded tube with internal and external flash removed and subsequently cold reduced to conform to the specified size and temper.

4.1.4 *Welded and Cold-Drawn Tube*—Forge-welded tube with internal and external flash removed and subsequently cold drawn over a plug or mandrel to the specified size and temper.

4.2 *Fusion-Welded Tube* manufactured as described in 6.2.2.

4.2.1 *As-Welded Tube*—Fusion-welded tube with no further refinement of grain structure.

4.2.2 *Welded and Annealed Tube*—Fusion-welded tube that has been annealed to produce a uniform grain size appropriate to the specified annealed temper. The structure of the weld zone shall be that which is typical of a fusion weld.

4.2.3 *Welded and Cold-Reduced Tube*—Fusion-welded tube subsequently cold-reduced to conform to the specified size and temper.

4.2.4 *Welded and Cold-Drawn Tube*—Fusion-welded tube subsequently cold-drawn over a plug or mandrel to the specified size and temper.

4.3 *Fully Finished Tube*—Welded tube with internal and external flash removed, if present, and subsequently cold-drawn over a plug or mandrel and annealed, and redrawn when necessary to conform to the specified temper.

5. Ordering Information

5.1 Orders for material under this specification shall include the following information:

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

5.1.2 Material (Sections 1, 6, and 7),

5.1.3 Temper (Section 8),

5.1.3.1 If tension tests are required (Section 9),

5.1.4 Whether a pressure test is to be used instead of the eddy-current test (see 15.1),

5.1.5 Dimensions, the diameter, wall thickness, whether minimum or nominal wall, and length, (Section 16),

5.1.6 Type of welded tube (Section 4),

5.1.7 Whether cut ends of the tube are to be deburred, chamfered, or otherwise treated (see 17.1),

5.1.8 If the product is to be subsequently welded (see Table 1 and Footnote C),

5.1.9 Specification number and year of issue,

5.1.10 Certification, if required (Section 24), and

5.1.11 Mill test report, if required (Section 26).

5.2 In addition, when material is purchased for agencies of the U.S. Government, it shall conform to the Supplementary Requirements as defined herein when specified in the contract or purchase order.

6. Materials and Manufacture

6.1 The material shall be of such quality and purity that the finished product shall have the properties and characteristics prescribed in this specification.

6.2 Welded tube shall be made of clean strip in either cold-rolled or annealed tempers. The strip shall be formed into a tubular shape on a suitable forming mill.

6.2.1 For forge-welded tube, the edges of the strip shall be heated to the required welding temperature, usually by high-frequency electric current, and be pressed firmly together causing a forge-type joint to be formed with internal and external flash or bead.

TABLE 1 Chemical Requirements

Copper or Copper Alloy UNS No.	Composition, %											
	Copper[A]	Nickel incl Cobalt	Lead, max	Iron	Zinc	Manganese	Aluminum	Phosphorus	Tin	Antimony	Arsenic	Other Elements
C10800	99.95[B] min	...	...	...	...	...	...	0.005–0.012	...	...	...	...
C12200	99.9 min	...	...	...	...	...	...	0.015–0.040	...	...	...	...
C19400	97.0–97.8	...	0.03	2.1–2.6	0.05–0.20	...	...	0.015–0.15	...	...	...	...
C23000	84.0–86.0	...	0.05	0.05 max	remainder	...	...	...	...	...	...	...
C44300	70.0–73.0	...	0.07	0.06 max	remainder	...	...	...	0.8–1.2	...	0.02–0.06	...
C44400	70.0–73.0	...	0.07	0.06 max	remainder	...	...	...	0.8–1.2	0.02–0.10	...	...
C44500	70.0–73.0	...	0.07	0.06 max	remainder	...	...	0.02–0.10	0.8–1.2	...	...	...
C68700	76.0–79.0	...	0.07	0.06 max	remainder	...	1.8–2.5	...	...	...	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[C]	1.0–1.8	1.0 max[C]	1.0 max	...	[C]	...	...	...	[C]
C71000	remainder	19.0–23.0	0.05[C]	0.50–1.0	1.0 max[C]	1.0 max	...	[C]	...	...	...	[C]
C71500	remainder	29.0–33.0	0.05[C]	0.40–1.0	1.0 max[C]	1.0 max	...	[C]	...	...	...	[C]
C71640	remainder	29.0–32.0	0.05[C]	1.7–2.3	1.0 max[C]	1.5–2.5	...	[C]	...	...	...	[C]
C72200[D]	remainder	15.0–18.0	0.05[C]	0.5–1.0	1.0 max[C]	1.0 max	...	[C]	...	...	...	[C,D]

[A] Silver counting as copper.

[B] Copper + silver + phosphorus.

[C] 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.

[D] Chromium 0.30 to 0.70.

6.2.1.1 The external flash (that portion of the weld which extends beyond the normal wall) shall always be removed.

6.2.1.2 The internal flash in forge-welded tube shall be removed to the extent that it shall not exceed 0.006 in. in height or 10 % of the nominal wall thickness, whichever is greater.

6.2.2 For fusion-welded tube, the edges of the strip shall be brought together and welded, usually by a GTAW welding process, without the addition of filler metal, causing a fusion-type joint to be formed with no internal or external flash or bead removal necessary.

6.2.3 Tube type, 4.3, fully finished tube, may be welded and subsequently processed by any method that would produce a tube suitable for subsequent cold-drawing and annealing.

6.2.4 There shall be no crevice in the weld seam visible to the unaided eye.

NOTE 2—The term "unaided eye" as used herein permits the use of corrective spectacles necessary to obtain normal vision.

7. Chemical Composition

7.1 The material shall conform to the 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 For Copper Alloy UNS No. C19400, 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.

7.2.2 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 %.

7.2.2.1 *Copper Alloy UNS Nos. C70400, C70600, C71000, C71500, and C71640*—When all the elements in Table 1 are analyzed, their sum shall be 99.5 % minimum.

7.2.2.2 *Copper Alloy UNS No. C72200*—When all the elements in Table 1 are analyzed, their sum shall be 99.8 % minimum.

7.2.3 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 %.

7.2.3.1 *Copper Alloy UNS No. C23000*—When all the elements in Table 1 are analyzed, their sum shall be 99.8 % minimum.

7.2.3.2 *Copper Alloy UNS Nos. C44300, C44400, and C44500*—When all the elements in Table 1 are analyzed, their sum shall be 99.6 % minimum.

7.2.3.3 *Copper Alloy UNS No. C68700*—When all the elements in Table 1 are analyzed, their sum shall be 99.5 % minimum.

8. Temper

8.1 Tube tempers shall be designated as follows:

8.1.1 Annealed tempers,

8.1.1.1 Welded and annealed,

8.1.1.2 Fully finished—annealed,

8.1.2 Light cold worked tempers,

8.1.2.1 As-welded from annealed strip,

8.1.2.2 As-welded, light cold worked, and

8.1.2.3 Fully finished—light drawn.

8.2 Other tempers shall be produced to the mechanical properties as agreed upon between the manufacturer or supplier and the purchaser.

8.3 Tubes of Copper Alloy UNS Nos. C23000, C44300, C44400, C44500, and C68700 shall be furnished in the annealed temper or the stress relieved condition as specified in the purchase order unless otherwise agreed upon between the purchaser and the manufacturer or supplier.

8.4 Tubes of Copper Alloy UNS Nos. C12200, C19400, C70400, C70600, C71000, C71500, C71640, and C72200 are normally supplied in the temper specified in the purchase order without stress relief treatment.

NOTE 3—Some 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 suggested that tubes of Copper Alloy UNS Nos. C23000, C44300, C44400, C44500, 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.

NOTE 4—The temper of 8.1.2.2 is to permit the production of a light cold-worked as-welded tube by means other than the use of annealed strip. Some of these, for example, are the use of annealed to temper strip, the use of lightly cold-rolled strip, and the use of cold-rolled strip and wherein the resulting tube is subsequently relief annealed.

9. Mechanical Properties

9.1 Tube specified to meet strength requirements shall have tensile properties as prescribed in Table 2.

10. Microscopical Examination

10.1 Samples of welded and annealed tube and of fully finished annealed tube shall be subjected to microscopical examination at a magnification of 75 diameters.

10.1.1 Forge-welded and annealed tube shall have a completely recrystallized grain structure, and the weld zone shall have a structure typical of hot-forged welds.

10.1.2 Fusion-welded and annealed tube shall have a completely recrystallized grain structure, and the weld zone shall have a structure typical of a fusion weld.

10.1.3 Fully finished and annealed tube shall have a completely recrystallized structure typical of the metal when cold-worked and annealed, including the weld zone.

10.2 Samples selected for test shall be examined microscopically at a magnification of 75 diameters to establish that the weld interface is metallurgically sound.

11. Expansion Test

11.1 Tubes supplied in the annealed temper (8.1.1) and the light cold-worked temper (8.1.2) and tubes supplied in the stress relieved condition shall pass the expansion test as specified in 11.2.

11.2 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 (see Note 2).

TABLE 2 Tensile Requirements

Copper or Copper Alloy UNS No.	Temper[A]		Tensile Strength, min, ksi[B]	Yield Strength at 0.5 % Extension Under Load, min, ksi[B]
	Designation	Name		
C10800, C12200	W061	annealed	30	9[C]
	WC55	light cold-worked	32	15
C19400	W061	annealed	45	15
	WC55	light cold-worked	45	22
C23000	W061	annealed	40	12
	WC55	light cold-worked	42	20
C44300, C44400, C44500	W061	annealed	45	15
	WC55	light cold-worked	50	35
C68700	W061	annealed	50	18
	WC55	light cold-worked	[D]	[D]
C70400	W061	annealed	38	12
	WC55	light cold-worked	40	30
C70600	W061	annealed	40	15
	WC55	light cold-worked	45	35
C71000	W061	annealed	45	16
	WC55	light cold-worked	50	35
C71500	W061	annealed	52	18
	WC55	light cold-worked	54	35
C71640	W061	annealed	63	25
	WC55	light cold-worked	75	40
C72200	W061	annealed	45	16
	WC55	light cold-worked	50	30

[A] When tempers listed in 8.1.2 are specified in the stress-relieved condition, the same properties as listed above shall apply.
[B] ksi = 1000 psi.
[C] Light straightening operation is permitted.
[D] Where no properties are shown, strength requirements shall be as agreed upon between the purchaser and the manufacturer or supplier.

TABLE 3 Expansion Requirements

Temper	Copper or Copper Alloy UNS No.	Expansion of Tube Outside Diameter, in Percent of Original Outside Diameter
Annealed	C10800	30
	C12200	30
	C19400	20
	C23000	20
	C44300, C44400, C44500	20
	C68700	20
	C70400	30
	C70600	30
	C71000	30
	C71500	30
	C71640	30
	C72200	30
Light cold-worked	C10800	20
	C12200	20
	C19400	20
	C70400	20
	C70600	20
	C71000	20
	C71500	20
	C71640	20
	C72200	20
Annealed and light cold-worked, stress relieved	C23000	20
	C44300, C44400, C44500	20
	C68700	20

12. Flattening Test

12.1 Test specimens at least 4 ft in length shall be flattened on different elements throughout the length 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 visible to the unaided eye (Note 2). The weld when visible or identifiable shall be placed in the position of maximum bend on one half of the flattened elements. When tubes are specified in a temper other than annealed (8.1.1), this test is required and may be made on annealed specimens.

13. Reverse Bend Test

13.1 A section 4 in. in length shall be split longitudinally 90° on each side of the weld. The sample shall then be opened and bent around a mandrel with a diameter four times the wall thickness, with the mandrel parallel to the weld and on the outside of the tube. The weld when visible or identifiable shall be at the point of maximum bend. There shall be no evidence of cracks, or lack of penetration in the weld, or of overlaps resulting from flash removal visible to the unaided eye (Note 2). When tubes are specified in a temper other than annealed (8.1.1), this test is required and may be made on annealed specimens.

14. Mercurous Nitrate Test

14.1 **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.

14.2 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 specimens shall include the finished tube end. The mercurous nitrate test is required for Copper Alloy UNS Nos. C23000,

C44300, C44400, C44500, and C68700 in the stress-relieved condition for tempers listed in 8.1.2.1, 8.1.2.2, and 8.1.2.3.

15. Nondestructive Testing

15.1 Each tube shall be subjected to an eddy-current test in 15.1.1. Fully finished tube (see 4.3) may be tested in the final drawn, annealed, or heat-treatment temper or in the drawn temper prior to the final anneal or heat treatment, unless otherwise agreed upon between the manufacturer or supplier and the purchaser. Tube supplied welded and annealed (see 4.2) may be tested in the welded condition before anneal or heat treatment, unless otherwise agreed upon between the manufacturer or supplier and the purchaser. The purchaser may specify either of the tests in 15.1.2 or 15.1.3 as an alternative to the eddy-current test.

15.1.1 *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 E 243, except as modified in 15.1.1.2.

15.1.1.1 The depth of the round-bottom transverse notches and the diameters of the drilled holes in the calibrating tube used to adjust the sensitivity of the test unit are shown in Table 4 and Table 5 respectively.

15.1.1.2 The discontinuities used to calibrate the test system may be placed in the strip from which the tube will be manufactured. These calibration discontinuities will pass through the continuous operations of forming, welding, and eddy-current testing. The test unit sensitivity required to detect the resultant discontinuities shall be equivalent to or greater than that required to detect the notches or drilled holes of Table 4 and Table 5 respectively, or other calibration discontinuities that may be used by mutual agreement between the manufacturer or supplier and the purchaser. Calibration discontinuities may be on the outside tube surface, the internal tube surface, or through the tube wall and shall be spaced to provide signal resolution adequate for interpretation. Each calibration discontinuity shall be detected by the eddy-current tester.

15.1.1.3 Tubes that do not actuate the signaling device of the eddy-current tester shall be considered as conforming 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 15.1.2, or the pneumatic test prescribed in 15.1.3. Tubes meeting requirements of either test shall be considered to conform if the tube dimensions are within the prescribed limits, unless otherwise agreed to by the manufacturer or supplier and the purchaser.

TABLE 4 Notch Depth

Tube Wall Thickness, in.	Tube Outside Diameter, in.		
	Over ¼ to ¾, incl	Over ¾ to 1¼, incl	Over 1¼ to 3⅛, 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 5 Diameter of Drilled Holes

Tube Outside Diameter	Diameter of Drilled Holes	Drill No.
in.	in.	
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

15.1.2 *Hydrostatic Test*—When specified, each tube selected in accordance with 15.1 shall withstand, without showing evidence of leakage, an internal hydrostatic pressure sufficient to subject the material to a fiber stress of 7000 psi, determined by the following equation for thin hollow cylinders under tension. The tube need not be tested at a hydrostatic pressure of over 1000 psig unless so specified.

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

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

15.1.3 *Pneumatic Test*—When specified, each tube shall be subjected to an internal air pressure of 60 psig minimum 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.

16. Dimensions and Permissible Variations

16.1 *Diameter*—The outside diameter of the tubes shall not vary from that specified by more than the amounts shown in Table 6 as measured by "go" and "no-go" ring gages. Where no values are shown in the table, dimensions shall be as agreed upon between the purchaser and the manufacturer or supplier.

16.2 *Wall Thickness Tolerances*:

16.2.1 *Tubes Ordered to Minimum Wall*— No tube at its thinnest point shall be less than the specified wall thickness or greater than the specified wall thickness plus twice the tolerance values shown in Table 7.

16.2.2 *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 Table 7.

16.3 *Length*—The length of the tubes shall not be less than that specified when measured at a temperature of 20°C, but may exceed the specified value by the amounts given in Table 8.

16.4 *Squareness of Cut*—The departure from squareness of the end of any tube shall not exceed the values shown in Table 9.

TABLE 6 Diameter Tolerances

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	0.004	0.004	0.004	0.0035	0.003
Over 0.740–1.000, incl	0.006	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] Thin wall thicknesses are supplied only in light cold-worked tubes.

TABLE 7 Wall Thickness Tolerances

Wall Thickness, in.	Outside Diameter, in.			
	Over ⅛ to ⅝, incl	Over ⅝ to 1, incl	Over 1 to 2, incl	Over 2 to 3.125, incl
	Wall Thickness Tolerances, Plus and Minus, in.			
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 0.135	0.007	0.007	0.0075	0.008

TABLE 8 Length Tolerances

Specified length, ft	Tolerance, all Plus, in.
Up to 15	3/32
Over 15–20, incl	⅛
Over 20–30, incl	5/32
Over 30–60, incl	⅜
Over 60–100, incl[A]	½

[A] Condenser tubes in lengths over 100 ft are not in present demand. Tolerance values for these lengths will be developed as experience dictates. Tolerance values for lengths in wall thicknesses of 0.020, incl to 0.032 shall be agreed upon between the manufacturer or supplier and the purchaser.

TABLE 9 Squareness of Cut

Tube Outside Diameter, in.	Tolerance
Up to ⅝, incl	0.010 in.
Over ⅝	0.016 in./in. of diameter

NOTE 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 dimension may be cause for rejection.

17. Workmanship, Finish, and Appearance

17.1 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.

17.2 Welded and annealed, fully finished annealed, or stress-relieved tubes shall be clean and smooth but may have a superficial, dull iridescent film on both the inside and the outside surfaces. All other tubes shall be clean and smooth but may have a superficial film of drawing or other lubricant on the surfaces.

18. Sampling

18.1 *Sampling*—The lot size, portion size, and selection of sample pieces shall be as follows:

18.1.1 *Lot Size*—600 tubes or 10 000 lb or a fraction of either, whichever constitutes the greater weight.

18.1.2 *Portion Size*—Sample pieces from two individual lengths of finished product.

18.2 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.

18.3 *Chemical Analysis*—Samples for chemical analysis shall be taken in accordance with Practice E 255. Drillings, millings, and so forth, shall be taken in approximately equal weight from each of the sample pieces selected in accordance with 18.1.2 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.

18.3.1 Instead of sampling in accordance with Practice E 255, 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 semi-finished 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:

18.3.1.1 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.

18.3.1.2 When samples are taken from the semi-finished product, a sample shall be taken to represent each 10 000 lb or fraction thereof, except that not more than one sample shall be required per piece.

18.3.2 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.

18.3.3 In the event that heat identification or traceability is required, the purchaser shall specify the details desired.

19. Number of Tests and Retests

19.1 *Tension Tests*—When tensile strength is specified, two tubes shall be selected from each lot and subjected to the tension test which shall, in case of disagreement, be made in accordance with Test Methods E 8.

19.2 *Other Tests*—For tests specified in Sections 10-14 inclusive, specimens shall be taken from each of the pieces selected in accordance with 18.1.

19.3 If any test specimen representing a lot fails to conform to the requirements of Sections 7, 10, 11, 12, 13, and 14, 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.

20. Test Methods

20.1 The properties and chemical compositions enumerated in this specification shall, in case of disagreement, be determined in accordance with the following test methods:

Test	ASTM Designation
Chemical analysis	E 53, E 54, E 62, E 75, E 478
Grain size	E 112
Expansion (pin test)	B 153
Mercurous nitrate	B 154
Tension	E 8

20.2 Tension test specimens shall be of the full section of the tube and shall conform to the requirements of the Significance and Use Section of Test Methods E 8, 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 E 8 may be used when a full section specimen cannot be tested.

20.3 Whenever tension test results are obtained from both full size and machined test specimens and they differ, the results obtained from full-size test specimens shall be used to determine conformance to the specification requirements.

20.4 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. Above the yield strength the movement per minute of the testing machine head under load should not exceed 0.5 in./in. of gage length (or distance between grips for full-section specimens).

20.5 The surface of the test specimen for microscopical examination of grain size shall approximate a radial longitudinal section of the tube.

20.6 The surface of the test specimen for microscopical examination of the weld interface shall approximate a transverse section of the tube.

21. Significance of Numerical Limits

21.1 For purposes of determining compliance with the specified limits for requirements of the properties listed in the following table, an observed value or a calculated value shall be rounded as indicated in accordance with the rounding method of Practice E 29.

Property	Rounded Unit for Observed or Calculated Value
Chemical composition	nearest unit in the last righthand place of figures
Tensile strength and yield strength	nearest ksi (up to 10 ksi, incl, over 10 to 100 ksi, incl)
Elongation	nearest 1 %
Grain size	nearest multiple of 0.005 mm

22. Inspection

22.1 The manufacturer shall afford the inspector all reasonable facilities to satisfy him that the tubes being furnished are in accordance with this specification. All tests (except check analysis) and inspection shall be made at the place of manufacture, prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

23. Rejection and Rehearing

23.1 Material that fails to conform to the requirements of this specification when inspected or tested by the purchaser or his agent may be rejected. Rejection should be reported to the manufacturer or supplier promptly and in writing. In case of dissatisfaction with the results of the test, the manufacturer or supplier may make claim for a rehearing.

24. Certification

24.1 When specified in the purchase order or contract, a manufacturer's certificate of compliance shall be furnished to the purchaser stating that each lot has been sampled, tested, and inspected in accordance with this specification and the requirements have been met. When material is specified to meet the requirements of *ASME Boiler and Pressure Vessel Code*, the certification requirements are mandatory.

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. Test Report

26.1 When specified in the purchase order or contract, the manufacturer or supplier shall furnish to the purchaser a manufacturer's test report showing the results of the required tests.

27. Keywords

27.1 condenser; copper; copper alloy; copper nickel; evaporator; heat exchanger; tube; welded

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:*

Fed. Std. No. 102 Preservation, Packaging and Packing Levels[5]

Fed. Std. No. 123 Marking for Shipment (Civil Agencies)[5]

Fed. Std. No. 185 Identification Marking of Copper and Copper-Base Alloy Mill Products[5]

S1.1.2 *Military Standard:*

MIL-STD-129 Marking for Shipment and Storage[5]

S1.1.3 *Military Specification:*

MIL-C-3993 Packaging of Copper and Copper-Base Alloy Mill Products[5]

S2. Quality Assurance

S2.1 *Responsibility for Inspection:*

S2.1.1 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 MIL-C-3993.

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.

[5] Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

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.

TABLE X1.1 Densities

Copper or Copper Alloy UNS No.	Density lb/in.^{3}
C10800	0.323
C12200	0.323
C19400	0.322
C23000	0.316
C44300, C44400, C44500	0.308
C68700	
C70400, C70600, C71000,	0.301
C71500, C71640, C72200	0.323