Designation: B 111/B 111M – 04

Standard Specification for Copper and Copper-Alloy Seamless Condenser Tubes and Ferrule Stock[1]

This standard is issued under the fixed designation B 111/B 111M; 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] establishes the requirements for seamless tube and ferrule stock of copper and various copper alloys up to 3⅛ in. [80 mm] inclusive, in diameter, for use in surface condensers, evaporators, and heat exchangers. The following coppers and copper alloys are specified:[3] (**Warning—**Mercury is a definite health hazard in use and disposal. (See 12.1.))

Copper or Copper Alloy UNS No.	Previously Used Designation	Description
C10100	OFE	Oxygen-free electronic
C10200	OF[A]	Oxygen-free without residual deoxidants
C10300	. . .	Oxygen-free, extra low phosphorus
C10800	. . .	Oxygen-free, low phosphorus
C12000	DLP[A]	Phosphorized, low residual phosphorus
C12200	DHP[A]	Phosphorized, high residual phosphorus
C14200	DPA[A]	Phosphorized, arsenical
C19200	. . .	Phosphorized, 1 % iron
C23000	. . .	Red Brass
C28000	. . .	Muntz Metal
C44300	. . .	Admiralty Metals, B, C, and D
C44400		
C44500		
C60800	. . .	Aluminum Bronze
C61300	. . .	. . .
C61400	. . .	Aluminum Bronze, D
C68700	. . .	Aluminum Brass, B
C70400	. . .	95-5 Copper-Nickel
C70600	. . .	90-10 Copper-Nickel
C70620	. . .	90-10 Copper-Nickel—Welding Grade
C71000	. . .	80-20 Copper-Nickel
C71500	. . .	70-30 Copper-Nickel
C71520	. . .	70-30 Copper-Nickel—Welding Grade
C71640	. . .	Copper-nickel-iron-manganese
C72200	. . .	. . .

[A] Designations listed in Classification B 224.

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

1.3 The following safety hazards caveat pertains only to the test methods portion, Section 19, of this specification: *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 The following documents in the current issue of the *Annual Book of ASTM Standards* form a part of this specification to the extent referenced herein:

2.2 *ASTM Standards:* [4]

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

B 154 Test Method for Mercurous Nitrate Test for Copper and Copper Alloys

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

B 224 Classification of Coppers

[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-111 in Section II of the Code.

[3] The UNS system for copper and copper alloys (see Practice E 527) is a simple expansion of the former standard designation system accomplished by the addition of a prefix "C" and a suffix "00." The suffix can be used to accommodate composition variations of the base alloy.

[4] 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.**

B 846 Terminology for Copper and Copper Alloys
B 858 Test Method for Ammonia Vapor Test for Determining Susceptibility to Stress Corrosion Cracking in Copper Alloys
E 8 Test Methods for Tension Testing of Metallic Materials
E 8M Test Methods for Tension Testing of Metallic Materials [Metric]
E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
E 53 Test Methods for Determination of Copper in Unalloyed Coppers by Gravimetry
E 54 Test Methods for Chemical Analysis of Special Brasses and Bronzes[5]
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 76 Test Methods for Chemical Analysis of Nickel-Copper Alloys[5]
E 112 Test Methods for Determining Average Grain Size
E 243 Practice for Electromagnetic (Eddy Current) Examination of Copper and Copper-Alloy Tubes
E 255 Practice for Sampling Copper and Copper Alloys for the Determination of Chemical Composition
E 478 Test Methods for Chemical Analysis of Copper Alloys
E 527 Practice for Numbering Metals and Alloys (UNS)

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms relating to copper and copper alloys, refer to Terminology B 846.

3.2 *Definition of Term Specific to This Standard:*

3.2.1 *capable of*—the test need not be performed by the producer of the material. However, should subsequent testing by the purchaser establish that the material does not meet these requirements, the material shall be subject to rejection.

4. Ordering Information

4.1 Include the following information when placing orders for product under this specification:

4.1.1 ASTM Designation and year of approval (for example, ASTM B 111/B 111M – 04),

4.1.2 Copper or Copper Alloy UNS Designation (see Table 1),

4.1.3 Form (tube or ferrule stock),

4.1.4 Temper (see Temper section),

4.1.5 Dimensions, outside diameter, and wall thickness, whether minimum or nominal (Dimensions and Permissible Variations Section),

4.1.6 Quantity—total weight or total length or number of pieces of each size, and

4.1.7 If product is purchased for agencies of the U.S. Government (see the Supplementary Requirements Section).

4.2 The following options are available and should be specified at the time of placing of the order when required:

4.2.1 Tension Test required per ASME Boiler and Pressure Vessel Code, Mechanical Properties section.

4.2.2 Pressure test as an alternative to eddy current test (Nondestructive Testing Section).

4.2.3 If the cut ends of the tubes do not need to be deburred (Workmanship, Finish, and Appearance section).

4.2.4 If the product is to be subsequently welded (Table 1, Footnotes G and H).

4.2.5 Residual Stress Test—Ammonia Vapor Test or Mercurous Nitrate Test (Performance Requirements Section).

4.2.6 For Ammonia Vapor Test, risk level (pH value) if other than 10.

4.2.7 Heat identification or traceability details (Number of tests and Retests section).

4.2.8 Certification (Certification Section).

4.2.9 Mill Test Report (Mill Test Report Section).

4.2.10 If a subsequent thermal treatment after straightening is required (Temper section).

5. Materials and Manufacture

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

5.2 *Manufacture*—The product shall be produced by processes such as casting, extrusion, drawing, annealing, straightening, trimming, and other processes which may produce a seamless tube in the specified condition.

6. Chemical Composition

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

6.2 These composition limits do not preclude the presence of other elements. Limits for unnamed elements may be established by agreement between manufacturer or supplier and purchaser.

6.2.1 *Copper Alloy UNS No. C19200*—Copper may be taken as the difference between the sum of all the elements analyzed and 100 %. When all the elements in Table 1 are analyzed, their sum shall be 99.8 % minimum.

6.2.2 For copper alloys in which copper is specified as the remainder, copper may be taken as the difference between the sum of all the elements analyzed and 100 %.

6.2.2.1 When all the elements in Table 1 are analyzed, their sum shall be as shown in the following table:

Copper Alloy UNS No.	Copper Plus Named Elements, % min
C60800	99.5
C61300	99.8
C61400	99.5
C70400	99.5
C70600 & C70620	99.5
C71000	99.5
C71500 & C71520	99.5
C71640	99.5
C72200	99.8

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

6.2.3.1 When all the elements in Table 1 are analyzed, their sum shall be as shown in the following table:

[5] Withdrawn.

TABLE 1 Chemical Requirements

Copper or Copper Alloy UNS No.	Composition, %												
	Copper[A]	Tin	Aluminum	Nickel, incl Cobalt	Lead, max	Iron	Zinc	Manganese	Arsenic	Antimony	Phosphorus	Chromium	Other Named Elements
C10100	99.99 min[B]	0.002 max	...	0.0010 max	0.0005 max	0.0010 max	0.0001 max	0.00005 max	0.0005 max	0.0004 max	0.0003 max	0.0001 max	[C]
C10200[D]	99.95 min	...	...	...	...	...	...	...	...	...	...	...	[D]
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	98.5 min	...	...	...	...	0.8–1.2	0.20 max	...	...	...	0.01–0.04	...	...
C23000	84.0–86.0	...	...	...	0.05	0.05 max	remainder	...	...	...	...	...	...
C28000	59.0–63.0	...	...	...	0.30	0.07 max	remainder	...	...	...	...	...	...
C44300	70.0–73.0	0.9–1.2	...	...	0.07	0.06 max	remainder	...	0.02–0.06	...	...	...	...
C44400	70.0–73.0	0.9–1.2	...	...	0.07	0.06 max	remainder	...	...	0.02–0.10	...	...	...
C44500	70.0–73.0	0.9–1.2	...	...	0.07	0.06 max	remainder	...	...	...	0.02–0.10	...	...
C60800	remainder	...	5.0–6.5	...	0.10	0.10 max	...	...	0.02–0.35	...	...	...	...
C61300	remainder	0.20–0.50	6.0–7.5	0.15 max	0.01	2.0–3.0	0.10 max	0.20 max	...	...	0.015 max	...	[F,G]
C61400	remainder	...	6.0–8.0	...	0.01	1.5–3.5	0.20 max	1.0 max	...	...	0.015 max	...	...
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	1.0 max	...	...	...	...	...
C70620	86.5 min	...	...	9.0-11.0	0.02	1.0-1.8	0.50 max	1.0 max	...	...	0.02 max	...	C.05 max S.02 max
C71000	remainder	...	...	19.0–23.0	0.05[H]	0.50–1.0	1.0 max[H]	1.0 max	...	...	[H]	...	[H]
C71500	remainder	...	...	29.0–33.0	0.05	0.40–1.0	1.0 max	1.0 max	...	...	...	...	...
C71520	65.0 min	...	...	29.0-33.0	0.02	0.40-1.0	0.50 max	1.0 max	...	...	0.02 max	...	C.05 max S.02 max
C71640	remainder	...	...	29.0–32.0	0.05[H]	1.7–2.3	1.0 max[H]	1.5–2.5	...	...	[H]	...	C.06 max S.03 max[H]
C72200	remainder	...	...	15.0–18.0	0.05[H]	0.50–1.0	1.0 max[H]	1.0 max	...	...	[H]	0.30–0.70	Si.03 max Ti.03 max[H]

[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] Impurity maximums in ppm for C10100 shall be: antimony 4, arsenic 5, bismuth 1, cadmium 1, iron 10, lead 5, manganese 0.5, mercury 1, nickel 10, oxygen 5, phosphorus 3, selenium 3, silver 25, sulfur 15, tellurium 2, tin 2, and zinc 1.

[D] Oxygen in C10200 shall be 10 ppm max.

[E] Copper plus sum of named elements shall be 99.95 % min.

[F] Silicon shall be 0.10 % max.

[G] When the product is for subsequent welding applications and is so specified by the purchaser, chromium shall be 0.05 % max, cadmium 0.05 % max, zinc 0.05 % max, and zirconium 0.05 % max.

[H] 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.

Copper Alloy UNS No.	Copper Plus Named Elements, % min
C23000	99.8
C28000	99.7
C44300	99.6
C44400	99.6
C44500	99.6
C68700	99.5

7. Temper

7.1 Tubes of Copper Alloy UNS Nos. C23000, C28000, C44300, C44400, C44500, C60800, C61300, C61400, C68700, and C71000 shall be furnished in the annealed (O61) temper unless otherwise specified on the purchase order.

7.2 Tubes of Copper Alloy UNS Nos. C71500, C71520, and C71640 shall be supplied in one of the following tempers as specified: (*1*) annealed (O61) or (*2*) drawn, and stress-relieved (HR50).

7.3 Tubes of Copper Alloy UNS Nos. C10100, C10200, C10300, C10800, C12000, C12200, and C14200 shall be supplied in any one of the following tempers, one of which shall be specified: (*1*) light-drawn (H55), (*2*) hard-drawn (H80), or (*3*) hard drawn and end annealed (HE80).

7.4 Tubes of Copper Alloy UNS No. C19200 shall be supplied in any one of the following tempers, one of which shall be specified: (*1*) annealed (O61), (*2*) light-drawn (H55), (*3*) hard-drawn (H80), or (*4*) hard-drawn, and end-annealed (HE80).

7.5 Tubes of Copper Alloy UNS Nos. C70400, C70600, C70620, and C72200 may be supplied in either light-drawn (H55) or annealed (O61) temper.

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

7.7 *Optional Post-Straightening Thermal Treatment*—Some tubes, when subjected to aggressive environments, may have the potential for stress-corrosion cracking failure due to the residual stresses induced during straightening processing. For such applications, it is suggested that tubes of Copper Alloy UNS Nos. C23000, C28000, C44300, C44400, C44500, C60800, C61300, C61400, and C68700 be subjected to a stress-relieving thermal treatment subsequent to straightening.

If required, this must be specified on the purchase order or contract. Tolerances for roundness and length, and the condition of straightness, for tube so ordered, shall be to the requirements agreed upon between the manufacturer and the purchaser.

8. Mechanical Properties

8.1 Material specified to meet the requirements of the *ASME Boiler and Pressure Vessel Code* shall have tensile properties as prescribed in Table 2 or Table 3.

9. Grain Size for Annealed Tempers

9.1 Grain size shall be a standard requirement for all product in the annealed (O61) temper.

9.1.1 Samples of annealed-temper tubes selected for test shall be subjected to microscopical examination per Test Methods E 112 at a magnification of 75 diameters and shall show uniform and complete recrystallization.

9.1.2 Products other than of Copper Alloy UNS Nos. C19200 and C28000 shall have an average grain size within the limits of 0.010 to 0.045 mm. These requirements do not apply to tubes of light-drawn (H55), hard-drawn (H80), hard-drawn and end-annealed (HE80), or drawn and stress-relieved tempers (HR50).

10. Expansion Test

10.1 Tube specimens selected for test shall withstand the expansion shown in Table 4 when expanded in accordance with Test Method B 153. The expanded tube shall show no cracking or rupture visible to the unaided eye.

10.2 Hard-drawn tubes not end annealed are not subject to this test. When tubes are specified end annealed, this test is required and shall be performed on the annealed ends of the sampled tubes.

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

11. Flattening Test

11.1 *Test Method*—Each test specimen shall be flattened in a press at three (3) places along the length, each new place to be rotated on its axis approximately one third turn from the last flattened area. Each flattened area shall be at least 2 in. in length. A flattened test-specimen shall allow a micrometer caliper set at three (3) times the wall thickness to pass freely over the flattened area. The flattened areas of the test specimen shall be inspected for surface defects.

11.2 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.

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

12. Residual Stress Test

12.1 A residual stress test is required to be performed only for Copper Alloy UNS Nos. C23000, C28000, C44300, C44400, C44500, C60800, C61300, C61400, and C68700.

12.2 Unless otherwise specified, the producer shall have the option of testing the product to either the mercurous nitrate test, Test Method B 154, or the ammonia vapor test, Test Method B 858, as prescribed below.

12.2.1 *Mercurous Nitrate Test*:

TABLE 2 Tensile Requirements—Inch-Pound Values

NOTE—See Table 3 for tensile requirements—SI values.

Copper or Copper Alloy UNS No.	Temper Designation		Tensile Strength, min ksi[A]	Yield Strength,[B] min ksi[A]	Elongation in 2 in., min %
	Standard	Former			
C10100, C10200, C10300, C10800, C12000, C12200, C14200	H55	light-drawn	36	30	...
C10100, C10200, C10300, C10800, C12000, C12200, C14200	H80	hard-drawn	45	40	...
C19200	H55	light-drawn	40	35	...
C19200	H80	hard-drawn	48	43	...
C19200	O61	annealed	38	12	...
C23000	O61	annealed	40	12	...
C28000	O61	annealed	50	20	...
C44300, C44400, C44500	O61	annealed	45	15	...
C60800	O61	annealed	50	19	...
C61300, C61400	O61	annealed	70	30	...
C68700	O61	annealed	50	18	...
C70400	O61	annealed	38	12	...
C70400	H55	light-drawn	40	30	...
C70600, C70620	O61	annealed	40	15	...
C70600, C70620	H55	light-drawn	45	35	...
C71000	O61	annealed	45	16	...
C71500, C70520	O61	annealed	52	18	...
C71500, C70520					
Wall thicknesses up to 0.048 in., incl	HR50	drawn and stress-relieved	72	50	12
Wall thicknesses over 0.048 in.	HR50	drawn and stress-relieved	72	50	15
C71640	O61	annealed	63	25	...
C71640	HR50	drawn and stress relieved	81	58	...
C72200	O61	annealed	45	16	...
C72200	H55	light-drawn	50	30	...

[A] ksi = 1000 psi.
[B] At 0.5 % extension under load.

TABLE 3 Tensile Requirements—SI Values

NOTE—See Table 2 for tensile requirements—inch-pound values.

Copper or Copper Alloy UNS No.	Temper Designation		Tensile Strength, min MPa	Yield Strength,[A] min MPa	Elongation in 50 mm, min %
	Standard	Former			
C10100, C10200, C10300, C10800, C12000, C12200, C14200	H55	light-drawn	250	205	. . .
C10100, C10200, C10300, C10800, C12000, C12200, C14200	H80	hard-drawn	310	275	. . .
C19200	H55	light-drawn	275	240	. . .
C19200	H80	hard-drawn	330	295	. . .
C19200	O61	annealed	260	85	. . .
C23000	O61	annealed	275	85	. . .
C28000	O61	annealed	345	140	. . .
C44300, C44400, C44500	O61	annealed	310	105	. . .
C60800	O61	annealed	345	130	. . .
C61300, C61400	O61	annealed	480	205	. . .
C68700	O61	annealed	345	125	. . .
C70400	O61	annealed	260	85	. . .
C70400	H55	light-drawn	275	205	. . .
C70600, C70620	O61	annealed	275	105	. . .
C70600, C70620	H55	light-drawn	310	240	. . .
C71000	O61	annealed	310	110	. . .
C71500, C71520	O61	annealed	360	125	. . .
C71500, C71520:					
Wall thicknesses up to 1.2 mm incl	HR50	drawn and stress-relieved	495	345	12
Wall thicknesses over 1.2 mm.	HR50	drawn and stress-relieved	495	345	15
C71640	O61	annealed	435	170	. . .
C71640	HR50	drawn and stress relieved	560	400	. . .
C72200	O61	annealed	310	110	. . .
C72200	H55	light-drawn	345	310	. . .

[A] At 0.5 % extension under load.

TABLE 4 Expansion Requirements

Temper Designation		Copper or Copper Alloy UNS No.	Expansion of Tube Outside Diameter, in Percent of Original Outside Diameter
Standard	Former		
O61	annealed	C19200	30
		C23000	20
		C28000	15
		C44300, C44400, C44500	20
		C60800	20
		C61300, C61400	20
		C68700	20
		C70400	30
		C70600, C70620	30
		C71000	30
		C71500, C71520	30
		C71640	30
		C72200	30
H55	light-drawn	C10100, C10200, C10300, C10800, C12000, C12200	20
		C14200	20
		C19200	20
		C70400	20
		C70600, C70620	20
		C72200	20
HR50	drawn and stress relieved	C71500, C71520	20
		C71640	20
. . .	hard-drawn and end annealed	C10100, C10200, C10300, C10800, C12000, C12200, C14200	30

12.2.1.1 **Warning**—Mercury is a definite health hazard and therefore equipment for the detection and removal of mercury vapor produced in volatilization is recommended. The use of rubber gloves in testing is advisable.

12.2.1.2 The test specimens, cut 6 in. [150 mm] in length, shall withstand without cracking, an immersion in the standard mercurous nitrate solution prescribed in Test Method B 154. The test specimen shall include the finished tube end.

12.2.2 *Ammonia Vapor Test*:

12.2.2.1 The test specimens, cut 6 in. [150 mm] in length, shall withstand without cracking ,the ammonia vapor test as prescribed in Test Method B 858. For the purposes of this specification, unless otherwise agreed between purchaser and supplier, the risk level identified in the Annex of Method B 858, shall be specified as risk level (pH value) of 10.

13. Nondestructive Testing

13.1 Each tube shall be subjected to the eddy-current test in 13.1.1. Tubes may be tested in the final drawn, annealed, or heat-treated temper or in the drawn temper before the final anneal or heat treatment unless otherwise agreed upon by the supplier and the purchaser. The purchaser may specify either of the tests in 13.1.2 or 13.1.3 as an alternative to the eddy-current test.

13.1.1 *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.

13.1.1.1 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 Tables 5 and 6, and Tables 7 and 8, respectively.

13.1.1.2 Tubes that do not actuate the signaling device of the eddy-current tester shall be considered to conform 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 13.1.2, or the pneumatic test prescribed in 13.1.3. Tubes meeting requirements of either test shall be considered to conform if the tube dimensions are within the prescribed limits, unless otherwise agreed upon between the manufacturer and the purchaser.

13.1.2 *Hydrostatic Test*—Each tube shall stand, without showing evidence of leakage, an internal hydrostatic pressure sufficient to subject the material to a fiber stress of 7000 psi [48 MPa] as determined by the following equation for thin hollow cylinders under tension. The tube need not be tested at a hydrostatic pressure of over 1000 psi [7.0 MPa] unless so specified.

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

where:

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

13.1.3 *Pneumatic Test*—Each tube shall be subjected to an internal air pressure of 60 psig [400 kPa], min, 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.

TABLE 5 Notch Depth—Inch-Pound Values

NOTE—See Table 6 for notch depth—SI values.

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 6 Notch Depth—SI Values

NOTE—See Table 5 for notch depth—inch-pound values.

Tube Wall Thickness, mm	Tube Outside Diameter, mm		
	Over 6 to 19, incl	Over 19 to 32, incl	Over 32 to 80, incl
Over 0.4–0.8	0.13	0.15	0.18
Incl 0.8–1.3	0.15	0.15	0.19
Incl 1.3–2.1	0.18	0.19	0.20
Incl 2.1–2.8	0.19	0.22	0.24
Incl 2.8–3.0	0.23	0.23	0.28

TABLE 7 Diameter of Drilled Holes—Inch-Pound Values

NOTE—See Table 8 for diameter of drilled holes—SI values.

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

TABLE 8 Diameter of Drilled Holes—SI Values

NOTE—See Table 7 for diameter of drilled holes—inch-pound values.

Tube Outside Diameter, mm	Diameter of Drilled Holes, mm	Drill No.
6.0–19.0, incl	0.65	72
Over 19.0–25.4, incl	0.80	68
Over 25.4–31.8, incl	0.92	64
Over 31.8–38.1, incl	1.1	58
Over 38.1–44.4, incl	1.2	56
Over 44.4–50.8, incl	1.3	55

14. Dimensions and Permissible Variations

14.1 *Diameter*—The outside of the tubes shall not vary from that specified by more than the amounts shown in Table 9 or Table 10 as measured by "go" and "no-go" ring gages.

14.2 *Wall Thickness Tolerances:*

14.2.1 *Tubes Ordered to Minimum Wall*—No tube wall at its thinnest point shall be less than the specified wall thickness. The maximum plus deviation from the specified wall at any point shall not exceed twice the values shown in Tables 11 and 12.

14.2.2 *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 Tables 11 and 12.

14.3 *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 Tables 13 and 14.

14.4 *Squareness of Cut*—The departure from squareness of the end of the tube shall not exceed the following: