



**Designation: B395/B395M – 16**

# Standard Specification for U-Bend Seamless Copper and Copper Alloy Heat Exchanger and Condenser Tubes<sup>1</sup>

This standard is issued under the fixed designation B395/B395M; 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 ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

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

## 1. Scope\*

1.1 This specification<sup>2</sup> establishes the requirements for condenser, evaporator, and heat exchanger U-bend tubes that are manufactured from seamless copper and copper alloy tube.

1.2 *Units*—The values stated in either SI units or inch-pound 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 This specification is applicable to product 2 in. [50 mm] or less, inclusive, in diameter.

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

Copper or Copper Alloy UNS No.	Previously Used Designation	Type of Metal
C10200	OF <sup>A</sup>	oxygen-free without residual deoxidants
C10300	...	oxygen-free, extra low phosphorus
C10800	...	oxygen-free, low phosphorus
C12000	DLP <sup>A</sup>	phosphorized, low residual phosphorus
C12200	DHP <sup>A</sup>	phosphorized, high residual phosphorus
C14200	DPA <sup>A</sup>	phosphorized, arsenical
C19200	...	phosphorized, 1 % iron
C23000	...	red brass
C44300	Type B	admiralty metal
C44400	Type C	admiralty metal
C44500	Type D	admiralty metal
C60800	...	aluminum bronze
C68700	Type B	aluminum brass
C70400	...	95-5 copper-nickel
C70600	...	90-10 copper-nickel

Copper or Copper Alloy UNS No.	Previously Used Designation	Type of Metal
C70620	...	90-10 copper-nickel (modified for welding)
C71000	...	80-20 copper-nickel
C71500	...	70-30 copper-nickel
C71520	...	70-30 copper-nickel (modified for welding)
C72200	...	copper-nickel

<sup>A</sup> Designations listed in Classification B224.

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

1.5.1 *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. (Warning—Mercury has been designated by many regulatory agencies as a hazardous substance that can cause serious medical issues. Mercury, or its vapor, has been demonstrated to be hazardous to health and corrosive to materials. Caution should be taken when handling mercury and mercury containing products. See the applicable product Safety Data Sheet (SDS) for additional information. Users should be aware that selling mercury and/or mercury containing products into your state or country may be prohibited by law.)*

## 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*:<sup>3</sup>

**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**

<sup>1</sup> 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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<sup>2</sup> For ASME Boiler and Pressure Vessel Code applications see related Specification SB-395 in Section II of that Code.

<sup>3</sup> 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**

- B224 Classification of Coppers
- B601 Classification for Temper Designations for Copper and Copper Alloys—Wrought and Cast
- B846 Terminology for Copper and Copper Alloys
- B858 Test Method for Ammonia Vapor Test for Determining Susceptibility to Stress Corrosion Cracking in Copper Alloys
- B900 Practice for Packaging of Copper and Copper Alloy Mill Products for U.S. Government Agencies
- B968/B968M Test Method for Flattening of Copper and Copper-Alloy Pipe and Tube
- 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)<sup>4</sup>
- E112 Test Methods for Determining Average Grain Size
- E118 Test Methods for Chemical Analysis of Copper-Chromium Alloys (Withdrawn 2010)<sup>4</sup>
- 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
- 2.3 Other Standards:<sup>5</sup>
- ASME Boiler and Pressure Vessel Code

### 3. Terminology

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

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *dual-gage tube, n*—a tube which has more than one wall-gage thickness contained within the length of the tube.

3.2.2 *squareness of cut, n*—the maximum deviation of one side of a cross section of tube from the opposite side, when measured against the projected perpendicularity of the plane of the projected center of the tube at the ends.

3.2.3 *u-bend tube, n*—a tube bent 180° in a single plane into a U-shape.

### 4. Ordering Information

4.1 Include the following specified choices when placing orders for product under this specification, as applicable:

- 4.1.1 ASTM designation and year of issue,
- 4.1.2 Copper or copper alloy UNS No. designation (Section 6),

<sup>4</sup>The last approved version of this historical standard is referenced on [www.astm.org](http://www.astm.org).

<sup>5</sup>Available from American Society of Mechanical Engineers (ASME), ASME International Headquarters, Two Park Ave., New York, NY 10016-5990, <http://www.asme.org>.

- 4.1.3 Temper (Section 7),
  - 4.1.4 *Dimensions*—X—diameter and wall thickness of the tube (see 12.1 and 12.2),
  - 4.1.5 Schedule of bending radii (must include the number of pieces of each radii) (see 12.2.5),
  - 4.1.6 Length of U-bend tube legs (see 12.2.8),
  - 4.1.7 If the product is to be subsequently welded (see Table 1), and
  - 4.1.8 Intended application, and
  - 4.1.9 If the product is to be for U.S. Government.
- 4.2 The following options are available but may not be included unless specified at the time of placing of the order when required:
- 4.2.1 Heat identification or traceability details (see 5.1.2).
  - 4.2.2 Tension test (see 9.1),
  - 4.2.3 Relief anneal of U-bent portion of copper-nickel U-bend tubes (see 7.6),
  - 4.2.4 Dual-gage, a schedule of tubes required in dual-gage and length of heavy gage section must be furnished with this option (see 5.2.2 and 12.2.3),
  - 4.2.5 Flattening Test (Section 10.2).
  - 4.2.6 Expansion Test (Section 10.1).
  - 4.2.7 Certification, if required (see Section 21), and
  - 4.2.8 Mill Test Report, if required (see Section 22).

4.3 If product is purchased for agencies of the U.S. Government, it shall be in accordance with the requirements specified in the Supplementary Requirements section, when specified in the contract or purchase order.

4.4 If product is ordered for ASME Boiler and Pressure Vessel Code Application (See Certification Section 21).

### 5. Materials and Manufacture

#### 5.1 Materials:

5.1.1 The material of manufacture shall be of the copper alloys defined in 1.4 and 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.

5.1.2 When specified in the contract or purchase order that heat identification or traceability is required, the purchaser shall specify the details desired.

NOTE 1—Due to the discontinuous nature of the processing of casting into wrought products, it is not always practical to identify a specific casting analysis with a specific quantity of material.

#### 5.2 Manufacture:

5.2.1 The product shall be manufactured by such hot working, cold working and annealing processes as to produce a uniform wrought structure in the finished product.

5.2.2 Tubes required to be U-bent to a small radius shall, if specified, be furnished as dual-gage tubes.

5.2.2.1 These tubes shall be made prior to U-bending with the wall thickness of the central section of the tube length, increased the equivalent of one Stubs' or Birmingham Wire Gage (BWG) thicker than the wall thickness specified for the straight leg portion of the U-bend tube.

5.2.2.2 Unless otherwise specified, dual-gage tubes shall be made to constant inside diameter; that is, the increased wall



TABLE 1 Chemical Requirements

Copper or Copper Alloy UNS No.	Composition, %											Other Named Elements	
	Copper	Tin	Aluminum	Nickel, incl Cobalt	Lead, max	Iron	Zinc	Manganese	Arsenic	Antimony	Phosphorus		Chromium
C10200 <sup>A,B</sup>	99.95 min	...	...	...	...	...	...	...	...	...	...	...	10 ppm max O
C10300 <sup>A</sup>	99.95 <sup>C</sup> min	...	...	...	...	...	...	...	...	...	...	...	...
C10800 <sup>A</sup>	99.95 <sup>C</sup> min	...	...	...	...	...	...	...	...	...	...	...	...
C12000 <sup>A</sup>	99.90 min	...	...	...	...	...	...	...	...	...	...	...	...
C12200 <sup>A</sup>	99.9 min	...	...	...	...	...	...	...	...	...	...	...	...
C14200 <sup>A</sup>	99.4 min	...	...	...	...	...	...	...	...	...	...	...	...
C19200 <sup>D</sup>	98.5 min	...	...	...	...	0.8-1.2	0.20 max	...	0.15-0.50	...	...	...	...
C23000 <sup>D</sup>	84.0-86.0	...	...	...	0.05 max	0.05 remainder	...	...	...	...	...	...	...
C44300 <sup>E</sup>	70.0-73.0	0.9-1.2	...	...	0.07 max	0.06 remainder	...	...	0.02-0.06	...	...	...	...
C44400 <sup>E</sup>	70.0-73.0	0.9-1.2	...	...	0.07 max	0.06 remainder	...	...	...	0.02-0.10	...	...	...
C44500 <sup>E</sup>	70.0-73.0	0.9-1.2	...	...	0.07 max	0.06 remainder	...	...	...	...	...	...	...
C60800 <sup>A,F</sup>	remainder	...	5.0-6.5	...	0.10 max	0.10 remainder	...	...	0.02-0.35	...	...	...	...
C68700 <sup>A,F</sup>	76.0-79.0	...	1.8-2.5	...	0.07 max	0.06 remainder	...	...	0.02-0.06	...	...	...	...
C70400 <sup>A,F</sup>	remainder	...	...	...	0.05 max	1.0 max	0.30 to 0.8 max <sup>G</sup>	...	...	...	...	...	...
C70600 <sup>A,F</sup>	remainder	...	...	...	0.05 max	1.0 max	1.0 max <sup>G</sup>	...	...	...	...	...	...
C70620 <sup>A,F</sup>	86.5 min	...	...	...	0.02 max	1.0-1.8	0.50 max	1.0 max	...	0.02 max	...	...	0.05C max 0.02S max <sup>G</sup>
C71000 <sup>A,F,G</sup>	remainder	...	...	...	0.05 <sup>G</sup> max	1.0 max	1.0 max <sup>G</sup>	1.0 max <sup>G</sup>	...	...	...	...	...
C71500 <sup>A,F</sup>	remainder	...	...	...	0.05 max	0.40-1.0	1.0 max	1.0 max	...	...	...	...	...
C71520 <sup>A,F</sup>	65.0 min	...	...	...	0.02 max	0.40-1.0	0.50 max	1.0 max	...	0.02 max	...	...	0.05C max 0.02S max <sup>G,H</sup>
C72200 <sup>A,D,G</sup>	remainder	...	...	...	0.05 <sup>G</sup> max	0.50-1.0	1.0 max <sup>G</sup>	1.0 max	...	...	0.30-0.70	...	...

<sup>A</sup> Silver counting as copper.

<sup>B</sup> This is a high conductivity copper which has, in the annealed condition, a minimum conductivity of 101 % IACS.

<sup>C</sup> Includes P.

<sup>D</sup> Cu + sum of named elements, 99.8 % min.

<sup>E</sup> Cu + sum of named elements, 99.6 % min.

<sup>F</sup> Cu + sum of named elements, 99.5 % min.

<sup>G</sup> When the product is for subsequent welding applications, and so specified by the purchaser, zinc shall be 0.50 % max, phosphorus 0.02 % max, sulfur 0.02 % max, and carbon 0.05 % max.

<sup>H</sup> Silicon shall be 0.03 % max, titanium shall be 0.03 % max.

thickness shall be obtained by increasing the outside diameter of the finished tube in the central heavy gage section.

5.2.3 The bent portion of the U-bend tube shall be substantially uniform in curvature.

## 6. Chemical Composition

6.1 The material shall conform to the chemical composition requirements specified in **Table 1** for the copper or copper alloy UNS No. designation specified in the ordering information.

6.1.1 Results of analysis on a product (check) sample shall conform to the composition requirements within the permitted analytical variance specified in **Table 1**.

6.2 These composition limits do not preclude the presence of unnamed elements. By agreement between the manufacturer and purchaser, limits may be established and analysis required for unnamed elements.

6.3 *Copper Alloy UNS No. C19200*—Copper may be taken as the difference between the sum of all the elements analyzed and 100 %.

6.4 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 %.

6.5 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. Temper

7.1 Tempers, as defined in Classification **B601**, are as follows:

7.2 Prior to U-bending, tubes of Copper Alloy UNS Nos. C23000, C44300, C44400, C44500, C60800, C68700, C70400, C70600, C70620, C71000, C71500, C71520, and C72200 shall be in the annealed temper (O61), unless otherwise specified in the purchase order.

7.3 Prior to bending, U-bend tubes of Copper Alloy UNS Nos. C10200, C10300, C10800, C12000, C12200, and C14200 shall be in light drawn temper (H55). Tubes of Copper Alloy UNS Nos. C70400, C70600, C70620, and C72200 shall, if specified, be made in the light-drawn temper (H55).

7.4 Prior to bending, U-bend tubes of Copper Alloy UNS No. C19200 shall be in the annealed (O61) or light drawn temper (H55) as specified.

7.5 Prior to bending, U-bend tubes of Copper Alloy UNS No. C71500 or C71520 shall be made in the drawn, stress-relieved temper (HR50), when specified.

7.6 The U-bend portion of tubes furnished in Copper Alloy UNS Nos. C23000, C44300, C44400, C44500, C60800, and C68700 shall be relief annealed (HR) after bending. If specified, the U-bend portion of tubes furnished in Copper Alloy UNS Nos. C70400, C70600, C70620, C71000, C71500, C71520, and C72200 shall be relief annealed (HR) after bending.

NOTE 2—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, C60800, and C68700 be subjected to a stress relieving (HR) 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 by the manufacturer and purchaser.

## 8. Grain Size for Annealed Tempers

8.1 Grain size shall be the standard requirement for all product in annealed tempers.

8.2 Acceptance or rejection based upon grain size shall depend only on the average grain size of a test specimen taken from each of two sample portions and each specimen shall be within the limits of 0.010 to 0.045 mm when determined in accordance with Test Methods **E112**.

8.3 The requirements of this section do not apply to product of the light-drawn temper (H55) drawn, stress-relieved temper (HR50), or to the U-bend portion of the product.

## 9. Mechanical Property Requirements

### 9.1 Tensile Strength Requirements:

9.1.1 Product specified to meet the requirements of *ASME Boiler and Pressure Vessel Code* shall have tensile properties as prescribed in **Table 2** for product specified in inch-pound units or **Table 3** for product specified in SI units. When tested in accordance with Test Methods **E8/E8M**.

## 10. Performance Requirements

### 10.1 Expansion Test:

10.1.1 When specified in the contract or purchaser order, tube specimens selected for test shall withstand the expansion shown in **Table 4** when expanded in accordance with Test Method **B153**.

10.1.2 The expanded tube shall show no cracking or other defects visible to the unaided eye.

### 10.2 Flattening Test:

10.2.1 When specified in the contract or purchase order, the flattening test in accordance with Test Method **B968/B968M** shall be performed.

10.2.2 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.

### 10.3 Residual Stress Test:

10.3.1 Product manufactured from Copper Alloy UNS Nos. C23000, C44300, C44400, C44500, C60800 and C68700 shall be tested for residual stress according to the requirements of Test Method **B154** or Test Method **B858** and show no signs of cracking.

**Warning**—Mercury is a definite health hazard. With the Mercurous Nitrate Test, equipment for the detection and removal of mercury vapor produced in volatilization, and the use of protective gloves is recommended.

10.3.2 When the Ammonia Vapor Test is used, the test pH value appropriate for the intended application shall be 10 unless otherwise specified by the purchaser.

10.3.3 Residual stress test specimens shall be from both the U-bend and straight leg length and tested without bending,

**TABLE 2 Tensile Requirements (Inch-Pound)**

 NOTE 1—For SI values, see [Table 3](#).

Copper or Copper Alloy UNS No.	Temper Designation		Tensile Strength, min, ksi <sup>B</sup>	Yield Strength, <sup>A</sup> min, ksi <sup>B</sup>	Elongation in 2 in., min, %
	Temper Code	Temper Name			
C10200, C10300, C10800, C12000, C12200, C14200	H55	light drawn	36	30	...
C19200	H55	light drawn	40	35	...
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	...
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, C71520	O61	annealed	52	18	...
For wall thicknesses up to 0.048 in., incl	HR50	drawn, stress-relieved	72	50	12
For wall thicknesses over 0.048 in.	HR50	drawn, stress-relieved	72	50	15
C72200	O61	annealed	45	16	...
C72200	H55	light drawn	50	45	...

**TABLE 3 Tensile Requirements (SI)**

 NOTE 1—For Inch-Pound values, see [Table 2](#).

Copper or Copper Alloy UNS No.	Temper Designation		Tensile Strength, min, MPa	Yield Strength, <sup>A</sup> min, MPa	Elongation in 50.8 mm, min, %
	Temper Code	Temper Name			
C10200, C10300, C10800, C12000, C12200, C14200	H55	light drawn	250	205	...
C19200	H55	light drawn	275	240	...
C19200	O61	annealed	260	85	...
C23000	O61	annealed	275	85	...
C44300, C44400, C44500	O61	annealed	310	105	...
C60800	O61	annealed	345	130	...
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	...
For wall thicknesses up to 1.2 mm, incl	HR50	drawn, stress-relieved	495	345	12
For wall thicknesses over 1.2 mm	HR50	drawn, stress-relieved	495	345	15
C72200	O61	annealed	310	110	...
C72200	H55	light drawn	345	310	...

springing, polishing, or any other preparation, except as allowed by the test method.

NOTE 3—A residual stress test provides information about the adequacy of the stress relief of the material. Stress relief annealing is a method of thermal stress relief. There is no standard test method to evaluate the effectiveness of a relief-anneal (HR) of the U-bend section of copper-nickel or copper-nickel-iron tubes with respect to stress-corrosion cracking susceptibility.

## 11. Other Requirements

### 11.1 Nondestructive Examination for Defects:

11.1.1 Each tube, prior to bending, shall be subjected to the eddy-current test.

11.1.2 Tubes may be tested in the final drawn, annealed, or heat-treated temper or in the drawn temper prior to the final anneal or heat treatment at the option of the manufacturer.

11.1.3 Testing shall follow the procedures of Practice [E243](#).

11.1.4 Unless otherwise agreed upon between the manufacturer, or supplier, and the purchaser, the manufacturer shall have the option of calibrating the test equipment using either notch-depth or drilled-hole standards. If agreement cannot be reached, notch-depth standard shall be utilized.

11.1.5 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 5](#) and [Table 7](#) for the material specified in the inch-pound system and [Table 6](#) and [Table 8](#) for material specified in the SI system.

11.1.6 Tubes that do not actuate the signaling device of the eddy-current tester shall be considered as conforming to the requirements of this test.



TABLE 4 Expansion Requirements

Temper Designation		Copper or Copper Alloy UNS No.	Expansion of Tube Outside Diameter in Percent Of Original Outside Diameter
Code	Name		
O61	annealed	C19200	30
		C23000	20
		C44300, C44400, C44500	20
		C60800	20
		C68700	20
		C70400	30
		C70600, C70620	30
		C71000	30
		C71500, C71520	30
		C72200	30
		H55	light-drawn
C14200	20		
C19200	20		
C70400	20		
C70600, C70620	20		
C72200	20		
C71500, C71520	20		
HR50	drawn, stress relieved	C71500, C71520	20

TABLE 5 Notch Depth

Tube Wall Thickness, in.	Tube Outside Diameter, in.		
	Over 1/4 to 3/4, incl	Over 3/4 to 1 1/4, incl	Over 1 1/4 to 2, 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)

Tube Wall Thickness, mm	Tube Outside Diameter, mm		
	Over 6 to 19, incl	Over 19 to 32, incl	Over 32 to 50, incl
Over 0.43–0.81	0.13	0.15	0.18
Incl, 0.81 to 1.3	0.15	0.15	0.19
Incl, 1.3 to 2.1	0.18	0.19	0.20
Incl, 2.1 to 2.8	0.19	0.22	0.24
Incl, 2.8 to 3.0	0.23	0.23	0.28

TABLE 7 Diameter of Drilled Holes

Tube Outside Diameter, in.	Diameter of Drilled Holes, in.	Drill No.
1/4 to 3/4, incl	0.025	72
Over 3/4, incl	0.031	68
Over 1–1 1/4, incl	0.036	64
Over 1 1/4 –1 1/2, incl	0.042	58
Over 1 1/2 –3/4, incl	0.046	56
Over 3/4, incl	0.052	55

11.1.7 Tubes causing irrelevant signals because of moisture, soil, and minor mechanical damage may be reconditioned and retested.

11.1.8 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.

11.1.9 Tubes causing irrelevant signals because of visible and identifiable handling marks shall be considered in confor-

TABLE 8 Diameter of Drilled Holes (SI)

Tube Outside Diameter, mm	Diameter of Drilled Holes, mm	Drill No.
6.0–19.0, incl	0.635	72
Over 19.0–25.0, incl	0.785	68
Over 25.0–32.0, incl	0.915	64
Over 32.0–38.0, incl	1.07	58
Over 38.0–45.0, incl	1.17	56
Over 45.0–50.0, incl	1.32	55

mance if the tube dimensions are within the prescribed limits and if the tubes conform to the leak test requirements of 11.2.2 or 11.2.3, unless otherwise agreed to by the manufacturer and purchaser.

11.2 Each U-bend tube shall be tested to the requirements of either 11.2.2 or 11.2.3.

11.2.1 Unless otherwise specified, the manufacturer shall have the option of the leak test to be used.

11.2.2 *Hydrostatic Test*—Each tube shall withstand an internal hydrostatic-pressure sufficient to subject the material to a fiber stress of 7000 psi [48 MPa] without evidence of leakage. The tube need not be tested at a hydrostatic pressure of over a gage pressure of 1000 psi [6.9 MPa], unless so specified. The stress shall be determined by the following equation for thin hollow cylinders under tension:

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

where:

$P$  = hydrostatic pressure, psi [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].

11.2.3 *Pneumatic Test*—Each tube shall be subjected to an internal air gage pressure of 60 psi [400 kPa], minimum. The product shall maintain pressure and show no evidence of leakage for 5 s. The test method used shall permit 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.

## 12. Dimensions, Mass, and Permissible Variations

12.1 *Tube Diameter*—The outside diameter of the straight leg portion of the tube, exclusive of the central heavy gage portion, shall not vary from that specified by more than the amounts shown in Table 9 for product specified in the inch-pound system or Table 10 for product specified in the SI system as measured by “go” and “no-go” ring gages.

### 12.2 Thickness:

12.2.1 *Tubes Ordered to Minimum Wall*—Prior to bending, the wall thickness of the single-gage tubes at the thinnest point shall not be less than the thickness specified. The maximum plus deviation from the specified wall at any point shall not exceed twice the value shown in Table 11 for product specified in the inch-pound system or Table 12 for product specified in the SI system.

### 12.2.2 Tubes Ordered to Nominal Wall: