Designation: B 395/B 395M – 02

Standard Specification for U-Bend Seamless Copper and Copper Alloy Heat Exchanger and Condenser Tubes[1]

This standard is issued under the fixed designation B 395/B 395M; 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 condenser, evaporator, and heat exchanger U-bends that are manufactured from seamless copper and copper alloy tube.

1.2 *Units*—The values stated in either inch-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 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[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
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
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

[A] Designations listed in Classification B 224.

1.5 The following pertains only to the test method described in Sections 11 and 15, 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 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:*

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

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

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

B 224 Classification of Coppers[3]

B 601 Practice for Temper Designations for Copper and Copper Alloys—Wrought and Cast[3]

B 846 Terminology for Copper and Copper Alloys[3]

B 858 Test Method for Ammonia Vapor Test for Determining Susceptibility to Stress Corrosion Cracking in Copper Alloys[3]

B 900 Practice for Packaging Copper and Copper Alloy Mill-Products for U.S. Government Agencies[3]

E 3 Practice for Preparation of Metallographic Specimens[4]

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

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

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

[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-395 in Section II of that Code.

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

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

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

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

E 53 Test Methods for Chemical Analysis of Copper[6]
E 54 Test Methods for Chemical Analysis of Special Brasses and Bronzes[6]
E 62 Test Methods for Chemical Analysis of Copper and Copper Alloys (Photometric Methods)[6]
E 75 Test Methods for Chemical Analysis of Copper-Nickel and Copper-Nickel-Zinc Alloys[6]
E 112 Test Methods for Determining Average Grain Size[4]
E 118 Test Methods for Chemical Analysis of Copper-Chromium Alloys[6]
E 243 Practice for Electromagnetic (Eddy-Current) Examination of Copper and Copper-Alloy Tubes[7]
E 255 Practice for Sampling Copper and Copper Alloys for Determination of Chemical Composition[6]
E 478 Test Methods for Chemical Analysis of Copper Alloys[7]

3. Terminology

3.1 For the definitions of terms related to copper and copper alloys, refer to Terminology B 846.

3.2 *Definitions:*

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

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

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *squareness of cut*—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.

4. Ordering Information

4.1 Orders for product under this specification shall include the following information:

4.1.1 ASTM designation and year of issue,

4.1.2 Copper or copper alloy UNS No. designation (Section 6),

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 (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 If the product is to be for U.S. Government.

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

4.2.1 Tension test (see 9.1),

4.2.2 Relief anneal of U-bent portion of copper-nickel U-bend tubes (see 7.6),

4.2.3 Dual-gage, a schedule of tubes required in dual-gage and length of heavy gage section must be furnished with this option (see 5.2.1 and 12.2.3),

4.2.4 Certification, if required (see 21), and

4.2.5 Mill Test Report, if required (see 22).

4.3 In addition, when material 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.

5. Materials and Manufacture

5.1 *Materials*:

5.1.1 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.

5.2 *Manufacture*:

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

5.2.1.1 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.

5.2.1.2 Unless otherwise specified, dual-gage tubes shall be made to constant inside diameter; that is, the increased wall thickness shall be obtained by increasing the outside diameter of the finished tube in the central heavy gage section.

5.2.2 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 specified in the ordering information.

6.2 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.

6.3 *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.

6.4 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 %.

6.4.1 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
C70400	99.5
C70600	99.5
C70620	99.5
C71000	99.5
C71500	99.5
C71520	99.5
C72200	99.8

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 %.

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

[6] *Annual Book of ASTM Standards*, Vol 03.05.
[7] *Annual Book of ASTM Standards*, Vol 03.06.

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
C10200[B]	99.95 min[C]	...	...	...	...	...	...	...	...	...	...	...	10 ppm max O
C10300	99.95[D] min	...	...	...	...	...	...	...	...	...	0.001–0.005	...	...
C10800	99.95[D] min	...	...	...	...	...	...	...	...	...	0.005–0.012	...	...
C12000	99.90 min	...	...	...	...	...	...	...	...	...	0.004–0.012	...	...
C12200	99.90 min	...	...	...	...	...	...	...	...	...	0.015–0.040	...	...
C14200	99.40 min	...	...	...	...	...	...	...	0.15–0.50	...	0.015–0.040	...	...
C19200[E]	98.5 min	...	...	...	...	0.8–1.2	0.20 max	...	...	...	0.01–0.04	...	...
C23000[F]	84.0–86.0	...	...	...	0.05	0.05 max	remainder	...	...	...	...	...	...
C44300[F]	70.0–73.0	0.9–1.2	...	...	0.07	0.06 max	remainder	...	0.02–0.06	...	...	...	...
C44400[F]	70.0–73.0	0.9–1.2	...	...	0.07	0.06 max	remainder	...	...	0.02–0.10	...	...	...
C44500[F]	70.0–73.0	0.9–1.2	...	...	0.07	0.06 max	remainder	...	...	...	0.02–0.10	...	...
C60800[G]	remainder	...	5.0–6.5	...	0.10	0.10 max	...	...	0.02–0.35	...	...	...	...
C68700[G]	76.0–79.0	...	1.8–2.5	...	0.07	0.06 max	remainder	...	0.02–0.06	...	...	...	...
C70400[G]	remainder	...	...	4.8–6.2	0.05	1.3–1.7	1.0 max	0.30 to 0.8	...	...	...	...	...
C70600[G]	remainder	...	...	9.0–11.0	0.05[H]	1.0–1.8	1.0 max[H]	1.0 max[H]	...	...	...	...	...
C70620[G]	86.5 min	...	...	9.0–11.0	0.02	1.0–1.8	0.50	1.0	...	...	...	...	0.05C 0.02P 0.02S
C71000[G]	remainder	...	...	19.0–23.0	0.05[H]	0.50–1.0	1.0 max	1.0 max[H]	...	...	[H]	...	[H]
C71500	remainder	...	...	29.0–33.0	0.05[H]	0.40–1.0	1.0 max[H]	1.0 max	...	...	...	...	[D]
C71520	65.0 min	...	...	29.0–33.0	0.02	0.40–1.0	0.50	1.0	...	...	...	...	0.05C 0.02P 0.02S
C72200[E]	remainder	...	...	15.0–18.0	0.05[H]	0.50–1.0	1.0 max[H]	1.0 max	...	...	...	0.30–0.70	[H,I]

[A] Silver counting as copper.
[B] This is a high conductivity copper which has, in the annealed condition, a minimum conductivity of 100 % IACS.
[C] Cu is determined by the difference in the impurity total ans 100 %.
[D] Includes P.
[E] Cu + sum of named elements, 99.8 % min.
[F] Cu + sum of named elements, 99.6 % min.
[G] Cu + sum of named elements, 99.5 % min.
[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.
[I] Silicon shall be 0.03 % max, titanium shall be 0.03 % max.

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

7. Temper

7.1 Tempers, as defined in Practice B 601, 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 1—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 of Annealed Tempers

8.1 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.

8.2 Materials other than Copper Alloy UNS No. C19200 shall have an average grain size within the limits of 0.010 to 0.045 mm.

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-bent portion of the product.

9. Mechanical Property Requirements

9.1 *Tensile Property 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.

10. Performance Requirements

10.1 *Expansion Test*:

Tube specimens selected for test shall withstand the expansion shown in Table 4 when expanded in accordance with Test Method B 153.

11. Other Requirements

11.1 *Flattening Test*—When specified in the contract or purchase order, the flattening test described in the Test Method section in 17.2.1.3 shall be performed.

11.1.1 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.

11.2 *Mercurous Nitrate Test or Ammonia Vapor Test*:

11.2.1 The mercurous nitrate or ammonia vapor test is required only for Copper Alloy UNS Nos. C23000, C44300, C44400, C44500, C60800, and C68700. (**Warning**—Mercury

TABLE 2 Tensile Requirements

Copper or Copper Alloy UNS No.	Temper Designation		Tensile Strength, min, ksi [B]	Yield Strength,[A] min, ksi [B]	Elongation in 2 in., min, %
	Standard	Former			
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)

Copper or Copper Alloy UNS No.	Temper Designation		Tensile Strength, min, MPa	Yield Strength,[A] min, MPa	Elongation in 50.8 mm, min, %
	Standard	Former			
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	...

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
		C44300, C44400, C44500	20
		C60800	20
		C68700	20
		C70400	30
		C70600, C70620	30
		C71000	30
		C71500, C71520	30
		C72200	30
H55	light-drawn	C10200, C10300, C10800, C12000, C12200	20
		C14200	20
		C19200	20
		C70400	20
		C70600, C70620	20
		C72200	20
HR58	drawn, stress relieved	C71500, C71520	20

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.)

11.2.2 The test specimens, cut 6 in. [150 mm] in length from both the U-bend and straight leg length, shall withstand, without cracking, an immersion in the standard mercurous nitrate solution in Test Method B 154 or immersion in the ammonia vapor solution as defined in Test Method B 858: the straight leg specimens shall include the finished tube ends.

NOTE 2—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.

11.2.3 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.

11.2.4 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.

11.3 *Nondestructive Examination for Defects*:

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

11.3.2 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.

11.3.3 Testing shall follow the procedures of Practice E 243.

11.3.4 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.

11.3.5 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.

TABLE 5 Notch Depth

Tube Wall Thickness, in.	Tube Outside Diameter, in.		
	Over ¼ to ¾ , incl	Over ¾ to 1¼ , incl	Over 1¼ 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

11.3.6 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 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.
¼ to ¾ , incl	0.025	72
Over ¾ , incl	0.031	68
Over 1–1¼ , incl	0.036	64
Over 1¼ –1½ , incl	0.042	58
Over ½ –¾ , incl	0.046	56
Over ¾ , incl	0.052	55

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

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

11.3.8 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.

11.3.9 Tubes causing irrelevant signals because of visible and identifiable handling marks shall be considered in conformance if the tube dimensions are within the prescribed limits and if the tubes conform to the leak test requirements of 11.4.2 or 11.4.3, unless otherwise agreed to by the manufacturer and purchaser.

11.4 Each U-bend tube shall be tested to the requirements of either 11.4.2 or 11.4.3.

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

11.4.2 *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].

11.4.3 *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*—

12.2.2.1 Prior to bending the maximum plus and minus deviation from the nominal wall at any point shall not exceed the values shown in Table 11 for product specified in the inch-pound system or Table 12 for product specified in the SI system.

12.2.2.2 When tubes are required in dual-gage, the wall thickness of the heavy gage portion, prior to bending, shall conform to the applicable tolerances in Table 11 or Table 12 for the specified heavier gage (Note 3).

NOTE 3—The wall thickness of the heavy-gage section of the dual-gage tube shall be determined by adding one half the difference between the outside diameter at the heavy gage and the outside diameter of the standard gage to the minimum measured wall thickness determined at either end of the tube.

12.2.3 *Wall Thickness of Tube in U-Bend Section*—The wall thickness of the tube at the apex of the U-bent section shall be not less than the value determined by the following equation:

$$t_f = t(2R)/(2R + D) \quad (2)$$

where:

t_f = thickness after bending, in. [mm],
t = specified thickness of minimum wall or specified nominal wall minus the permissible wall thickness tolerance, in. [mm],
R = centerline bend radius, in. [mm], and
D = nominal outside diameter of the tube, in. [mm]

Proof of conformance to this requirement shall be obtained by bending a tube specimen representative of the material offered to the scheduled radius of bend cutting the tube at the apex of the bend, measuring the tube wall at the cross section