Designation: B163 – 22

Standard Specification for Seamless Nickel and Nickel Alloy Condenser and Heat-Exchanger Tubes[1]

This standard is issued under the fixed designation B163; 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 U.S. Department of Defense.

1. Scope*

1.1 This specification[2] covers seamless tubes of nickel and nickel alloys, as shown in Table 1, for use in condenser and heat-exchanger service.

1.2 This specification covers outside diameter and average wall, or outside diameter and minimum wall tube.

1.2.1 The sizes covered by this specification are 3 in. (76.2 mm) and under in outside diameter with minimum wall thicknesses of 0.148 in. (3.76 mm) and under, and with average wall thicknesses of 0.165 in. (4.19 mm) and under.

1.3 Tube shall be furnished in the alloys and conditions as shown in Table 2. For small diameter and light wall tube (converter sizes), see Appendix X2.

1.4 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.5 The following safety hazards caveat pertains only to the test method portion, Section 12, 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 become familiar with all hazards including those identified in the appropriate Safety Data Sheet (SDS) for this product/material as provided by the manufacturer, to establish appropriate safety, health, and environmental practices, and determine the applicability of regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

B829 Specification for General Requirements for Nickel and Nickel Alloys Seamless Pipe and Tube

B880 Specification for General Requirements for Chemical Check Analysis Limits for Nickel, Nickel Alloys and Cobalt Alloys

E8/E8M Test Methods for Tension Testing of Metallic Materials

E18 Test Methods for Rockwell Hardness of Metallic Materials

E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

E76 Test Methods for Chemical Analysis of Nickel-Copper Alloys (Withdrawn 2003)[4]

E112 Test Methods for Determining Average Grain Size

E140 Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop Hardness, Scleroscope Hardness, and Leeb Hardness

E1473 Test Methods for Chemical Analysis of Nickel, Cobalt and High-Temperature Alloys

2.2 *Federal Standards:*[5]

Fed. Std. No. 102 Preservation, Packaging and Packing Levels

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

Fed. Std. No. 182 Continuous Identification Marking of Nickel and Nickel-Base Alloys

2.3 *Military Standard:*[5]

MIL-STD-129 Marking for Shipment and Storage

[1] This specification is under the jurisdiction of ASTM Committee B02 on Nonferrous Metals and Alloys and is the direct responsibility of Subcommittee B02.07 on Refined Nickel and Cobalt and Their Alloys.

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[2] For ASME Boiler and Pressure Vessel Code applications see related Specification SB-163 in Section II of that Code.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

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

[5] Available from DLA Document Services, Building 4/D, 700 Robbins Ave., Philadelphia, PA 19111-5094, http://quicksearch.dla.mil.

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

TABLE 1 Chemical Requirements[A]

Element	Composition,%									
	N02200	N02201	N04400	N06025	N06045	N06600	N06601	N06603	N06686	N06690
Nickel	99.0 min[B]	99.0 min[B]	63.0 min[B]	remainder[B]	45.0 min[B]	72.0 min[B]	58.0–63.0	remainder[B]	remainder[B]	58.0 min[B]
Copper	0.25	0.25	28.0 – 34.0	0.1	0.3	0.5	1.0	0.5	...	0.5
Molybdenum	...	...	...	...	...	...	...	...	15.0 – 17.0	...
Iron	0.40	0.40	2.5	8.0 – 11.0	21.0 – 25.0	6.0 – 10.0	remainder[B]	8.0 – 11.0	5.0	7.0 – 11.0
Manganese	0.35	0.35	2.0	0.15	1.0	1.0	1.0	0.15	0.75	0.5
Carbon	0.15	0.02	0.3	0.15 – 0.25	0.05 – 0.12	0.15	0.10	0.20 – 0.40	0.010	0.05
Silicon	0.35	0.35	0.5	0.5	2.5 – 3.0	0.5	0.5	0.5	0.08	0.5
Sulfur	0.01	0.01	0.024	0.010	0.010	0.015	0.015	0.010	0.02	0.015
Chromium	...	...	...	24.0 – 26.0	26.0 – 29.0	14.0 – 17.0	21.0 – 25.0	24.0 – 26.0	19.0 – 23.0	27.0 – 31.0
Aluminum	...	...	...	1.8 – 2.4	...	...	1.0 – 1.7	2.4 – 3.0	...	...
Titanium	...	...	...	0.1 – 0.2	...	...	...	0.01 – 0.25	0.02 – 0.25	...
Phosphorus	...	...	...	0.020	0.020	...	...	0.02	0.04	...
Cerium	...	...	...	...	0.03 – 0.09	...	...	...	...	...
Zirconium	...	...	...	0.01 – 0.10	...	...	...	0.01 – 0.10	...	...
Yttrium	...	...	...	0.05 – 0.12	...	...	...	0.01 – 0.15	...	...
Boron	...	...	...	...	...	...	...	...	...	...
Cobalt	...	...	...	...	...	...	...	...	...	...
Niobium[C]	...	...	...	...	...	...	...	...	...	...
Tungsten	...	...	...	...	...	...	...	...	3.0 – 4.4	...
Nitrogen	...	...	...	...	...	...	...	...	...	...

[A] Maximum unless range or minimum is given. Where ellipses (...) appear in this table, there is no requirement and analysis for the element need not be determined or reported.
[B] Element shall be determined arithmetically by difference.
[C] Columbium and niobium are interchangeable names for the same element and both names are acceptable for use in B02.07 specifications.

TABLE 1 Chemical Requirements[A] *(continued)*

Element	Composition, %									
	N06696	N06699	N06845	N08120	N08800	N08801	N08810	N08811	N08825	N08935
Nickel	remainder[B]	remainder[B]	44.0 – 50.0	35.0 – 39.0	30.0 – 35.0	30.0 – 34.0	30.0 – 35.0	30.0 – 35.0	38.0 – 46.0	34.0 – 36.0
Copper	1.5 – 3.0	0.50	2.0 – 4.0	0.50	0.75	0.50	0.75	0.75	1.5 – 3.0	0.4
Molybdenum	1.0 – 3.0	...	5.0 – 7.0	2.50	...	...	...	...	2.5 – 3.5	6.1 – 7.1
Iron	2.0 – 6.0	2.5	remainder[B]	remainder[B]	39.5 min[B]	39.5 min[B]	39.5 min[B]	39.5 min[B]	22.0 min[B]	remainder[B]
Manganese	1.0	0.50	0.5	1.5	1.5	1.50	1.5	1.5	1.0	1.2
Carbon	0.15	0.005 – 0.10	0.05	0.02 – 0.10	0.10	0.10	0.05 – 0.10	0.06 – 0.10	0.05	0.030
Silicon	1.0 – 2.5	0.50	0.5	1.0	1.0	1.00	1.0	1.0	0.5	0.5
Sulfur	0.010	0.01	0.010	0.03	0.015	0.015	0.015	0.015	0.03	0.020
Chromium	28.0 – 32.0	26.0 – 30.0	20.0 – 25.0	23.0 – 27.0	19.0 – 23.0	19.0 – 22.0	19.0 – 23.0	19.0 – 23.0	19.5 – 23.5	26.0 – 28.0
Aluminum	...	1.9 – 3.0	...	0.40	0.15 – 0.60	...	0.15 – 0.60	0.25 – 0.60[D]	0.2	...
Titanium	1.0	0.60	...	0.20	0.15 – 0.60	0.75 – 1.5	0.15 – 0.60	0.25 – 0.60[D]	0.6 – 1.2	...
Phosphorus	...	0.02	...	0.04	0.045	...	0.045	0.045	...	0.030
Cerium	...	...	...	...	...	...	...	...	...	...
Zirconium	...	0.10	...	...	...	...	...	...	...	...
Yttrium	...	...	...	...	...	...	...	...	...	...
Boron	...	0.008	...	0.010	...	...	...	...	...	...
Cobalt	...	...	...	3.0	...	...	...	...	...	...
Niobium[C]	...	0.50	...	0.4 – 0.9	...	...	...	...	...	...
Tungsten	...	...	2.0 – 5.0	2.50	...	...	...	...	...	...
Nitrogen	...	0.05	...	0.13 – 0.30	...	...	...	...	...	0.25 – 0.36

[A] Maximum unless range or minimum is given. Where ellipses (...) appear in this table, there is no requirement and analysis for the element need not be determined or reported.
[B] Element shall be determined arithmetically by difference.
[C] Columbium and niobium are interchangeable names for the same element and both names are acceptable for use in B02.07 specifications.
[D] Alloy UNS N08811: Al + Ti = 0.85 – 1.20.

TABLE 2 Alloy and Conditions

Alloy	Condition
Nickel UNS N02200 and low-carbon nickel UNS N02201	annealed or stress-relieved
Nickel-copper alloy UNS N04400	annealed or stress-relieved
Nickel-chromium-iron-aluminum alloy UNS N06603	annealed
Nickel-chromium-iron-copper alloy UNS N06696	annealed
Nickel-chromium-iron-aluminum alloy UNS N06601	annealed
Nickel-chromium-iron alloy UNS N06600	annealed
Low-carbon nickel-chromium-molybdenum-tungsten alloy UNS N06686	annealed
Nickel-chromium-iron alloy UNS N06690	annealed
Nickel-chromium-iron alloy UNS N06045	annealed
Nickel-iron-chromium alloy UNS N08120[A]	annealed or cold-worked
Nickel-iron-chromium alloy UNS N08800[A]	annealed or cold-worked
Nickel-iron-chromium alloy UNS N08810[A]	annealed
Nickel-iron-chromium alloy UNS N08811[A]	annealed
Nickel-iron-chromium alloy UNS N08801	annealed
Nickel-iron-chromium-molybdenum alloy UNS N08935	annealed
Nickel-iron-chromium-molybdenum-copper alloy UNS N08825	annealed
Nickel-chromium-iron alloy UNS N06025	annealed
Nickel-iron-chromium-molybdenum-copper alloy UNS N06845	annealed
Nickel-chromium-aluminum alloy UNS N06699	annealed

[A] Alloy UNS N08800 is normally employed in service temperatures up to and including 1100 °F (593 °C). Alloys UNS N08810, UNS N08811, and UNS N08120 are normally employed in service temperatures above 1100 °F (539 °C) where resistance to creep and rupture is required, and it is annealed to develop controlled grain size for optimum properties in this temperature range.

3. Terminology

3.1 *Definitions:*

3.1.1 *average diameter, n*—average of the maximum and minimum outside diameters, as determined at any one cross section of the tube.

3.1.2 *tube, n*—hollow product of round or any other cross section having a continuous periphery.

4. Ordering Information

4.1 It is the responsibility of the purchaser to specify all requirements that are necessary for the safe and satisfactory performance of material ordered under this specification. Examples of such requirements include, but are not limited to, the following:

4.1.1 *Alloy* (Table 1).

4.1.2 *Condition (Temper)* Table 3 and Appendix X1 and Appendix X2.

4.1.2.1 If annealed ends for stress relieved tubing are desired, state length of end to be annealed and whether or not one end or both ends are to be annealed.

4.1.3 *Finish.*

4.1.4 *Dimensions*—Outside diameter, minimum or average wall thickness (in inches, not gage number), and length.

4.1.5 *Fabrication Operations:*

4.1.5.1 *Cold Bending or Coiling.*

4.1.5.2 *Packing.*

4.1.5.3 *Rolling or Expanding into Tube Sheets.*

4.1.5.4 *Welding or Brazing*—Process to be employed.

4.1.5.5 *Hydrostatic Test or Nondestructive Electric Test*—Specify type of test (6.5).

4.1.5.6 *Pressure Requirements*—If other than required by 6.5.

4.1.5.7 *Ends*—Plain ends cut and deburred will be furnished.

4.1.6 *Supplementary Requirements*—State nature and details.

4.1.7 *Certification*—State if certification is required (Section 15).

4.1.8 *Samples for Product (Check) Analysis*—Whether samples for product (check) analysis shall be furnished.

4.1.9 *Purchaser Inspection*—If purchaser wishes to witness tests or inspection of material at place of manufacture, the purchase order must so state indicating which tests or inspections are to be witnessed (Section 13).

4.1.10 *Small-Diameter and Light-Wall Tube (Converter Sizes)*—See Appendix X2.

5. Chemical Composition

5.1 The material shall conform to the composition limits specified in Table 1.

5.2 If a product (check) analysis is performed by the purchaser, the material shall conform to the product (check) analysis per Specification B880.

6. Mechanical Properties and Other Requirements

6.1 *Mechanical Properties*—The material shall conform to the mechanical properties specified in Table 3.

6.2 *Hardness*—When annealed ends are specified for tubing in the stress-relieved condition (see Table 3), the hardness of the ends after annealing shall not exceed the values specified in Table 3.

6.3 *Flare*—A flare test shall be made on one end of 1 % of the number of finished tube lengths from each lot. For less than 100 tubes in a lot, a flare test shall be made on one end of one tube length in the lot. In the case of stress relieved tubing with annealed ends, the test shall be made prior to, or subsequent to, annealing of the ends at the option of the manufacturer.

6.3.1 The flare test shall consist of flaring a test specimen with an expanding tool having an included angle of 60° until the specified outside diameter has been increased by 30 %. The flared specimen shall not exhibit cracking through the wall.

6.4 *Grain Size*—A transverse sample representing full-wall thickness of annealed alloys UNS N08120, UNS N08810 and UNS N08811 shall conform to an average grain size of ASTM No. 5 or coarser.

TABLE 3 Mechanical Properties of Tubes

Material and Condition	Tensile Strength, min, ksi (MPa)	Yield Strength (0.2 % Offset), min, ksi (MPa)	Elongation in 2 in. or 50 mm (or 4 *D*) min, %	Rockwell Hardness (or equivalent) for annealed ends[A]
Nickel UNS N02200:				
Annealed	55 (379)	15 (103)	40	...
Stress-relieved	65 (448)	40 (276)	15	B65 max
Low-carbon nickel UNS N02201:				
Annealed	50 (345)	12 (83)	40	...
Stress-relieved	60 (414)	30 (207)	15	B62 max
Nickel-copper alloy UNS N04400:				
Annealed	70 (483)	28 (193)	35	...
Stress-relieved	85 (586)	55 (379)	15	B75 max
Nickel-chromium-iron alloys:				
Annealed alloy UNS N06600	80 (552)	35 (241)	30	...
Annealed alloy UNS N06601	80 (552)	30 (207)	30	...
Annealed alloy UNS N06690	85 (586)	35 (241)	30	...
Annealed alloy UNS N06045	90 (620)	35 (240)	35	...
Annealed alloy UNS N06025	98 (680)	39 (270)	30	...
Annealed alloy UNS N06603	94 (650)	43 (300)	25	...
Annealed alloy UNS N06696	85 (586)	35 (240)	30	...
Low-carbon nickel-chromium-molybdenum-tungsten alloy:				
Annealed UNS N06686	100 (690)	45 (310)	45	...
Nickel-iron-chromium alloys:				
Annealed alloy UNS N08120	90 (620)	40 (276)	30	...
Annealed alloy UNS N08800	75 (517)	30 (207)	30	...
Annealed alloy UNS N08801	65 (448)	25 (172)	30	...
Cold-worked alloy UNS N08800	83 (572)	47 (324)	30	...
Annealed alloy UNS N08810	65 (448)	25 (172)	30	...
Annealed alloy UNS N08811	65 (448)	25 (172)	30	...
Nickel-iron-chromium-molybdenum alloy:				
Annealed alloy UNS N08935	109 (750)	62 (425)	35	...
Nickel-iron-chromium-molybdenum-copper alloys:				
Annealed UNS N08825	85 (586)	35 (241)	30	...
Annealed UNS N06845	100 (690)	40 (276)	30	...
Nickel-chromium-aluminum alloys:				
Annealed UNS N06699	89 (610)	35 (240)	40	...

[A] Rockwell or equivalent hardness values apply only to the annealed ends of stress-relieved tubing. Caution should be observed in using the Rockwell test on thin material, as the results may be affected by the thickness of specimen. For thickness under 0.050 in. (1.27 mm) the use of the Rockwell superficial or the Vickers hardness test is suggested. For hardness conversions for nickel and high-nickel alloys see Hardness Conversion Tables E140.

6.5 *Hydrostatic or Nondestructive Electric Test*—Each tube shall be subjected to either the hydrostatic test or the nondestructive electric test. The type of test to be used shall be at the option of the manufacturer, unless otherwise specified in the purchase order.

6.5.1 *Hydrostatic Test:*

6.5.1.1 Each tube with an outside diameter ⅛ in. (3.2 mm) and larger and tubes with wall thickness of 0.015 in. (0.38 mm) and over shall be tested by the manufacturer to an internal hydrostatic pressure of 1000 psi (6.9 MPa) provided that the fiber stress calculated in accordance with the following equation does not exceed the allowable fiber stress, *S*, indicated below. The tube shall show no evidence of leakage.

$$P = 2St/D$$

where:

- P = hydrostatic test pressure, psi (MPa),
- S = allowable fiber stress for material in the condition furnished, as follows:
- t = minimum wall thickness, in. (mm); equal to the specified average wall minus the permissible "minus" wall tolerance, Table 4 and Table X2.2, or the specified minimum wall thickness, and
- D = outside diameter of the tube, in. (mm).

	psi	MPa
Annealed low-carbon nickel UNS N02201	8 000	55.2
Stress-relieved low-carbon nickel UNS N02201	15 000	103.4
Annealed nickel UNS N02200	10 000	68.9
Stress-relieved nickel UNS N02200	16 200	111.7
Annealed nickel-copper alloy UNS N04400	17 500	120.6
Stress-relieved nickel-copper alloy UNS N04400	21 200	146.2
Annealed nickel-chromium-aluminum alloy UNS N06699	22 100	152
Annealed nickel-chromium-iron alloy UNS N06600	20 000	137.9
Annealed nickel-chromium-iron alloy UNS N06601	20 000	137.9
Annealed nickel-chromium-iron alloy UNS N06690	21 200	146
Annealed nickel-chromium-iron alloy UNS N06045	22 500	155
Annealed nickel-chromium-iron alloy UNS N06025	24 500	169
Solution annealed low-carbon nickel-chromium-molybdenum-tungsten alloy UNS N06686	25 000	172
Annealed nickel-chromium-iron-aluminum alloy UNS N06603	24 000	165
Annealed nickel-chromium-iron-copper alloy UNS N06696	21 200	146
Annealed nickel-iron-chromium alloy UNS N08120	22 500	155
Annealed nickel-iron-chromium alloy UNS N08800	18 700	128.9
Annealed nickel-iron-chromium alloy UNS N08810	16 600	114.4
Annealed nickel-iron-chromium alloy UNS N08811	16 600	114.4
Annealed nickel-iron-chromium alloy UNS N08801	16 600	114.4
Annealed nickel-iron-chromium-molybdenum alloy UNS N08935	27 200	187.5
Annealed nickel-iron-chromium-molybdenum copper alloy UNS N08825	21 000	144.8
Annealed nickel-iron-chromium-molydenum-copper alloy UNS N06845	21 200	146.2
Cold-worked nickel-iron-chromium alloy UNS N08800	20 700	142.7

TABLE 4 Permissible Variations in Outside Diameter and Wall Thickness of Condenser and Heat Exchanger Tubes

NOTE 1—The tolerances in the table apply to individual measurements of outside diameter and include out-of-roundness (ovality), and apply to all materials and all conditions, except that for thin wall tubes having a nominal wall of 3 % or less of the outside diameter, the mean outside diameter shall comply with the permissible variations of the above table and individual measurements (including ovality) shall conform to the plus and minus values of the table with the values increased by ½ % of the nominal outside diameter.

NOTE 2—*Eccentricity*—The variation in wall thickness in any one cross section of any one tube shall not exceed plus or minus 10 % of the actual (measured) average wall of that section. The actual average wall is defined as the average of the thickest and thinnest wall of that section.

NOTE 3—For tolerances of small diameter and light wall tube (converter sizes) see Appendix X2 (Table X2.2).

Material	Nominal Outside Diameter, in. (mm)	Permissible Variations[A]					
		Outside Diameter, in. (mm)		Wall Thickness,%			
				Average Wall		Minimum Wall	
		+	−	+	−	+	−
UNS N02200, UNS N02201, and UNS N04400	½ to ⅝ (12.7 to 15.9), excl	0.005 (0.13)	0	12.5	12.5	25.0	0
	⅝ to 1½ (15.9 to 38.1), incl	0.005 (0.13)	0.005 (0.13)	10.0	10.0	20.0	0
	over 1½ to 3 (38.1 to 76.2), incl	0.010 (0.25)	0.010 (0.25)	10.0	10.0	22.0	0
UNS N06600, UNS N06601, UNS N06690, UNS N06045, UNS N06025, UNS N06603, UNS N06696, UNS N08800, UNS N06699 UNS N08810, UNS N08811, UNS N08801, UNS N08935 UNS N08825, UNS N06845, and UNS N08120	½ to ⅝ (12.7 to 15.9), excl	0.005 (0.13)	0.005 (0.13)	12.5	12.5	25.0	0
UNS N06686	⅝ to 1½ (15.9 to 38.1), incl	0.0075 (0.19)	0.0075 (0.19)	10.0	10.0	20.0	0
	over 1½ to 3 (38.1 to 76.2), incl	0.010 (0.25)	0.010 (0.25)	10.0	10.0	22.0	0

[A] Wall variations as indicated above are applicable only to the wall as ordered, for instance, to minimum or to average wall, but not to both.

6.5.1.2 When so agreed upon between the manufacturer and the purchaser, tube may be tested to 1½ times the above allowable fiber stress.

6.5.1.3 When stress-relieved tubes with annealed ends are to be tested hydrostatically, such pressure testing shall be done prior to annealing of the ends of the tube.

6.5.2 *Nondestructive Electric Test*—Each tube shall be examined with a nondestructive electric test as prescribed in Specification B829.

7. Dimensions and Permissible Variations

7.1 *Outside Diameter and Wall Thickness*—The permissible variations in the outside diameter and wall thickness of tube shall not exceed those prescribed in Table 4 and Table X2.2, as applicable. (See also Table 5 and Table 6.)

7.2 *Length*—When tube is ordered cut-to-length, the length shall not be less than that specified, but a variation of plus ⅛ in. (3.2 mm) will be permitted, except that for lengths over 30 ft (9.1 m), a variation of plus ¼ in. (6.4 mm) will be permitted.

7.3 *Straightness*—Material shall be reasonably straight and free of bends or kinks.

8. Workmanship, Finish, and Appearance

8.1 The material shall be uniform in quality and temper, smooth, commercially straight, and free of injurious imperfections.

9. Sampling

9.1 *Lot*—Definition:

9.1.1 A lot for chemical analysis shall consist of one heat.

TABLE 5 Alloy,[A] Condition, Tube Size, and Bend Radii Limitations

Tube OD, in. (mm)	Average Tube Wall, in. (mm)[B]	Minimum Bend Radius, in. (mm)	
		Annealed Condition	Stress-Relieved Condition
Up to ½ (12.7), incl	0.046 to 0.057 (1.17 to 1.45), incl	1 3/16 (30.2)	1¼ (31.8)
Up to ½ (12.7), incl	Over 0.057 to 0.120 (1.45 to 3.05), incl	1 (25.4)	1⅛ (28.6)
Over ½ to ⅝ (12.7 to 15.9), incl	0.037 to 0.057 (0.94 to 1.45), incl	1 3/16 (30.2)	1¼ (31.8)
Over ½ to ⅝ (12.7 to 15.9), incl	Over 0.057 to 0.120 (1.45 to 3.05), incl	1 (25.4)	1 3/16 (30.2)
Over ⅝ to ¾ (15.9 to 19.0), incl	0.049 to 0.057 (1.24 to 1.45), incl	1¼ (31.8)	1½ (38.1)
Over ⅝ to ¾ (15.9 to 19.0), incl	Over 0.057 to 0.109 (1.45 to 2.77), incl	1 3/16 (30.2)	1¼ (31.8)
Over ¾ to 1 (19.0 to 25.4), incl	0.049 to 0.058 (1.24 to 1.47), incl	2 (50.8)	4 (101.6)
Over ¾ to 1 (19.0 to 25.4), incl	Over 0.058 to 0.109 (1.47 to 2.77), incl	1¾ (44.5)	2¼ (57.2)

[A] Applies for all alloys except alloy UNS N08810, alloy UNS N08801, and UNS N08811.

[B] To determine the bend radius applicable to minimum wall tubing, compute the corresponding average wall from the wall tolerances in Table 4, then use Table 5.

TABLE 6 Alloys, Size Ranges, and Yield Strength for Higher Yield Strength Tubes

Alloys	Size Range, in. (mm)		0.2 % Yield Strength, ksi (MPa)	
	OD	Wall Thickness	Minimum	Maximum
Nickel-chromium-iron Alloy UNS N06600	¼ to ⅞ (6.35 to 22.23)	Up to 0.100 (2.54)	40 (276)	65 (448)
Nickel-chromium-iron Alloy UNS N06601	¼ to ⅞ (6.35 to 22.23)	Up to 0.100 (2.54)	40 (276)	65 (449)
Nickel-iron-chromium Alloy UNS N08800	¼ to ⅞ (6.35 to 22.23)	Up to 0.100 (2.54)	40 (276)	65 (448)
Nickel-chromium-iron Alloy UNS N06690	¼ to ⅞ (6.35 to 22.23)	Up to 0.100 (2.54)	40 (276)	65 (448)

9.1.2 A lot for mechanical properties, hardness, flaring, and grain size testing shall consist of all material from the same heat, nominal size (except length), and condition (temper).

9.1.2.1 Where material cannot be identified by heat, a lot shall consist of not more than 500 lb (230 kg) of material in the same condition (temper) and size.

9.2 *Test Material Selection:*

9.2.1 *Chemical Analysis*—Representative samples shall be taken during pouring or subsequent processing.

9.2.1.1 Product (check) analysis shall be wholly the responsibility of the purchaser.

9.2.2 *Mechanical Properties, Hardness, and Grain Size*—Samples of the material to provide test specimens for mechanical properties, hardness, and grain size shall be taken from such locations in each lot as to be representative of that lot.

10. Number of Tests

10.1 *Chemical Analysis*—One test per lot.

10.2 *Mechanical Properties*—One test per lot.

10.3 *Hardness*—A representative sample consisting of 3 % of each lot of tubes with annealed ends (see 9.1.2).

10.4 *Grain Size*—One test per lot.

10.5 *Flare*—A representative sample consisting of 1 % of the number of tube lengths in each lot, with a minimum of one tube per lot.

11. Specimen Preparation

11.1 *Tension Test:*

11.1.1 Tension test specimens shall be taken from material in the final condition (temper) and tested in the direction of fabrication.

11.1.2 Whenever possible, all tubes shall be tested in full tubular size. When testing in full tubular size is not possible, longitudinal strip specimens, or the largest possible round specimen, shall be used. In the event of disagreement when full tubular testing is not possible, a longitudinal strip specimen with reduced gage length as contained in Test Methods E8/E8M shall be used.

11.1.3 In the case of stress-relieved tubes furnished with annealed ends, the tension test shall be made on the stress-relieved tubes prior to annealing the ends.

11.2 *Hardness Test:*

11.2.1 *Stress-Relieved Tubing with Annealed Ends*—The hardness test may be made on the inside of the tube near the end or on a specimen cut from the end, at the option of the manufacturer. The test shall be made on the inside of the specimen.

12. Test Methods

12.1 The chemical composition, mechanical, and other properties of the material as enumerated in this specification shall be determined, in case of disagreement, in accordance with the following methods:

Test	ASTM Designation
Chemical Analysis	E76, E1473
Tension	E8/E8M
Rounding Procedure	E29
Rockwell Hardness	E18
Grain Size	E112
Hardness Conversion	E140

12.2 The measurement of average grain size may be carried out by the planimetric method, the comparison method, or the intercept method described in Test Methods E112. In case of dispute the "referee" method for determining average grain size shall be the planimetric method.

12.3 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 below, in accordance with the rounding method of Practice E29:

Test	Rounded Unit for Observed or Calculated Value
Chemical composition, hardness, and tolerances (when expressed in decimals)	nearest unit in the last right-hand place of figures of the specified limit
Tensile strength, yield strength	nearest 1000 psi (6.9 MPa)
Elongation	nearest 1 %
Grain size:	
0.0024 in. (0.060 mm) or larger	nearest multiple of 0.0002 in. (0.005 mm)
less than 0.0024 in. (0.060 mm)	nearest multiple of 0.0001 in. (0.002 mm)

13. Inspection

13.1 Inspection of the material shall be made as agreed upon between the manufacturer and the purchaser as part of the purchase contract.

14. Rejection and Rehearing

14.1 Material not conforming to this specification or to authorized modifications will be subject to rejection.

14.2 Samples tested in accordance with this specification that represent rejected material shall be preserved for not less than three weeks from the date of the test report. In case of dissatisfaction with the results of the tests, the manufacturer may make claim for a rehearing within that time.

15. Certification

15.1 When specified in the purchase order or contract, a manufacturer's certification shall be furnished to the purchaser stating that material has been manufactured, tested, and inspected in accordance with this specification, and that the test

results on representative samples meet specification requirements. When specified in the purchase order or contract, a report of the test results shall be furnished.

16. Product Marking

16.1 Each bundle or shipping container shall be marked with the name of the material; condition (temper); this specification number; the size; gross, tare, and net weight; consignor and consignee address; contract or order number; or such other information as may be defined in the contract or order.

17. Keywords

17.1 seamless tube; UNS N02200; UNS N02201; UNS N04400; UNS N06025; UNS N06045; UNS N06600; UNS N06601; UNS N06603; UNS N06686; UNS N06690; UNS N06696; UNS N06845; UNS N08120; UNS N08800; UNS N08801; UNS N08810; UNS N08811; UNS N08825; UNS N06699; UNS N08935

SUPPLEMENTARY REQUIREMENTS

S1. U-BENT TUBES

The following supplementary requirements shall apply when U-bent tubes are specified by the purchaser in the inquiry, contract, or order.

S1.1 Limitation of Supplementary Requirements for U-Bent Tubes

S1.1.1 The requirements for U-bent tubes included in this supplement are limited to the alloys, conditions (tempers), tube outside diameter (OD), and wall thickness ranges and bend radii listed in Table 5.

S1.2 Permissible Variations in Dimensions (Fig. S1.1)

S1.2.1 *Leg Spacing*—The leg spacing, measured between the points of tangency of the bend to the legs shall not vary from the value (2*R* − specified tube OD) by more than the amounts shown below where *R* is the specified centerline bend radius:

Centerline Bend Radius (*R*), in. (mm)	Tolerance, in. (mm)
Up to 18 (457), incl	1/16 (1.6)
Over 18 to 30 (457 to 762), incl	3/32 (2.4)
Over 30 to 36 (762 to 914), incl	1/8 (3.2)

S1.2.2 *Diameter of Tube in U-Bent Section*—Neither the major, nor the minor outside diameter of the tube at any one cross section included within the points of tangency of the bend shall deviate from the nominal diameter prior to bending by more than 10 %.

S1.2.3 *Wall Thickness of Tube in U-Bent 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:

$$TF = T(2R)/(2R+D)$$

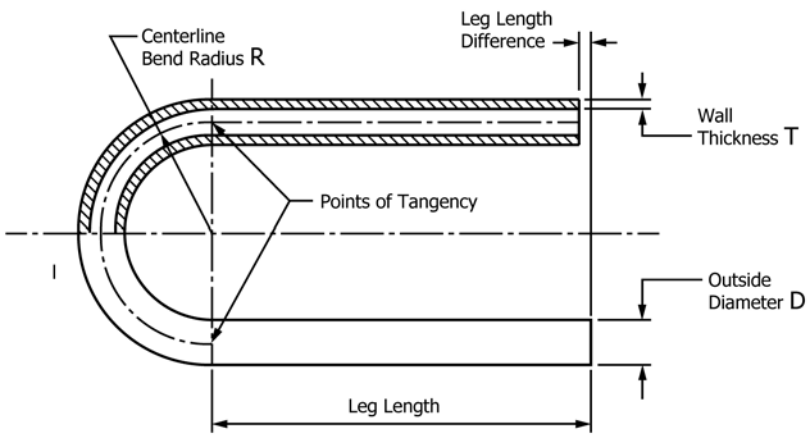

FIG. S1.1 Bent Portion of U-Tube

where:

TF = thickness after bending, in. (mm),
T = minimum permissible thickness of tube wall prior to bending, in. (mm),
R = centerline bend radius, in. (mm), and
D = nominal outside diameter of the tube, in. (mm).

When specified by the purchaser, 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 of this apex section, and comparing the measured value with the calculated value of *TF*.

S1.2.4 *Length of U-Bend Tube Legs*—The length of the tube legs as measured from the point of tangency of the bend and the tube leg to the end of the tube leg shall not be less than that specified, but may exceed the specified values by the following amounts:

Specified Length (*L*), ft (m)	Tolerance (all Plus), in. (mm)
Up to 20 (6.1), incl	1/8 (3.2)
Over 20 to 30 (6.1 to 9.1), incl	5/32 (4.0)
Over 30 to 60 (9.1 to 18.3), incl	1/4 (6.4)
Over 60 (18.3)	3/8 (10.0)

S1.2.4.1 The difference in the length of the tube legs shall not be greater than 1/8 in. (3.2 mm).

S1.2.5 *Squareness of Ends*—The end of any tube may depart from square by not more than the following amounts:

Tube OD, in. (mm)	Tolerance, in. (mm)
Up to 5/8 (15.9), incl	0.010 (0.25)
Over 5/8 (15.9)	0.016 (0.41)

S1.3 Hydrostatic Test

S1.3.1 When specified by the purchaser, the hydrostatic test shall be performed after bending. The minimum holding time at pressure shall be 5 s.

S1.3.1.1 When hydrostatic testing is performed after bending, such testing will not be required on straight length tubes prior to bending.

S1.3.1.2 The required fiber stress for computing hydrostatic test pressure shall be 26 600 psi (183.3 MPa).

S2. HIGH YIELD STRENGTH TUBES

The following supplementary requirements shall apply when high yield strength tubes are specified by the purchaser in the inquiry, contract, or purchase order.

S2.1 Limitations of Supplementary Requirements for High Yield Strength Tubes

S2.1.1 The requirements for higher yield strength tubes included in this supplement are limited to the alloys, tube outside diameter (OD), and wall thickness ranges listed in Table 6.

S2.2 Higher Yield Strength

S2.2.1 The 0.2 % yield strength shall be as listed in Table 6. All other mechanical properties shall be as listed in Table 3.

S2.3 Degree of Cold Work

S2.3.1 No additional cold working over and above that normally required for these alloys shall be used in order to meet the higher yield strength.

S2.4 Annealing

S2.4.1 Tubing is to be furnished in the annealed condition. In order to meet the higher yield strength requirement, it may be necessary to control the final annealing parameters so as to preclude large grain sizes.

S2.5 Marking Requirements

S2.5.1 In addition to the marking requirements of SB-163, the marking shall include the letters HYS signifying higher yield strength.

S3. COILED OR UNSTRAIGHTENED TUBING

The following supplementary requirements shall apply when coiled or unstraightened tubing is specified by the purchaser in the inquiry, contract, or purchase order.

S3.1 Unstraightened Tubing

S3.1.1 When the purchaser specifies coiled or unstraightened tubing after final heat treatment, the tensile specimens may be machine straightened prior to testing.

S3.1.2 On the certification and wherever the grade designation for unstraightened tubing appears, it shall be identified with the suffix letter "U" (for example, UNS N06600–U).

S4. U.S. GOVERNMENT

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.

S4.1 Referenced Documents

S4.1.1 The following documents of the issue in effect on date of material purchased form a part of this specification to the extent referenced herein: Fed. Std. No. 102, Fed. Std. No. 123, Fed. Std. No. 182, and MIL-STD-129.

S4.2 Quality Assurance

S4.2.1 *Responsibility for Inspection:*

S4.2.1.1 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 ensure that the material conforms to prescribed requirements.

S4.3 Identification Marking

S4.3.1 The material shall be properly marked for identification in accordance with Fed. Std. No. 182 except that the ASTM specification number and the alloy number shall be used.

S4.4 Preparation for Delivery

S4.4.1 *Preservation, Packaging, Packing:*

S.4.4.1.1 *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.

S4.4.1.2 *Civil Agencies*—The requirements of Fed. Std. No. 102 shall be referenced for definitions of the various levels of packaging protection.

S4.4.2 *Marking:*

S4.4.2.1 *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.

S4.4.2.2 *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.

APPENDIXES

(Nonmandatory Information)

X1. CONDITION AND FINISHES NORMALLY SUPPLIED

X1.1 Scope

X1.1.1 This appendix lists the conditions and finishes in which tube (other than converter sizes) are normally supplied. These are subject to change and the manufacturer should be consulted for the latest information available.

X1.2 Nickel UNS N02200

X1.2.1 *Annealed*—Soft, with a dull matte finish.

X1.2.2 *Stress Relieved*—Thermally treated below the annealing temperature to relieve the major portion of the internal stresses, with a thin, light to medium-dark surface.

X1.2.3 *Stress Relieved with Annealed Ends*—Same as X1.2.2 except with annealed ends.

X1.3 Low-Carbon Nickel UNS N02201

X1.3.1 *Annealed*—Similar to X1.2.1.

X1.3.2 *Stress Relieved*—Similar to X1.2.2.

X1.3.3 *Stress-Relieved With Annealed Ends*—Same as X1.3.2 except with annealed ends.

X1.4 Nickel-Copper Alloy UNS N04400

X1.4.1 *Annealed*—Soft with a dull matte finish.

X1.4.2 *Stress Relieved*—Thermally treated below the annealing temperature to relieve the major portion of the internal stresses resulting from cold drawing, with a thin, light to medium-dark surface.

X1.4.3 *Stress-Relieved With Annealed Ends*—Same as X1.4.2 except with annealed ends.

X1.5 Nickel-Chromium-Aluminum Alloy UNS N06699, Nickel-Chromium-Iron Alloy UNS N06600, Nickel-Chromium-Iron Alloy UNS N06601, Nickel-Chromium-Iron Alloy UNS N06690, Nickel-Chromium-Iron Alloy UNS N06045, Nickel-Chromium-Iron Alloy UNS N06025, Nickel-Iron-Chromium Alloys (UNS N08120, UNS N08800, UNS N08810, UNS N08811, and UNS N08801), Nickel-Iron-Chromium-Molybdenum Alloy N08935, and Nickel-Iron-Chromium-Molybdenum-Copper Alloys UNS N08825 and UNS N06845

X1.5.1 *Annealed and Ground Outside Diameter*—The inside diameter may have a bright finish when material is annealed in protective atmosphere; otherwise, the inside diameter is supplied descaled as necessary.

X1.5.2 *Annealed and Pickled (Not Ground)*—Outside and inside diameter will have dull, matte (pickled) surfaces.

X2. CONVERTER SIZES

X2.1 Small diameter and light wall tube in outside diameters 1¼ in. (31.8 mm) and under all wall thicknesses may be furnished in the following conditions or tempers when so specified. The material is furnished in a limited range of sizes and the manufacturer should be consulted as to the various outside diameters and wall thicknesses that may be furnished. Material shall be clean and scale-free. Such material shall conform to the applicable requirements indicated in Table X2.1 and Table X2.2.

TABLE X2.1 Mechanical Properties[A] of Small Diameter and Light Wall Tube

Material	Tensile Strength, ksi (MPa)	Yield Strength (0.2 % offset),[B] min, ksi (MPa)	Elongation in 2 in. or 50 mm, min, %	Rockwell Hardness[C] (Scale as Indicated)
Nickel				
UNS N02200:				
Annealed[D]	80 (552) max	15 (103)	33	B75, max
Half-hard[E]	80 (552) min	40 (276)	12	B75 to B90
Full hard[F]	95 (655) min	75 (517)	4	B90 to C30
Low-carbon nickel				
UNS N02201:				
Annealed[D]	70 (483) max	12 (83)	35	B62, max
Half-hard[E]	70 (483) min	30 (207)	12	B70 to B85
Full hard[F]	85 (586) min	65 (448)	4	B80 to B95
Nickel-copper alloy				
UNS N04400:				
Annealed[D]	90 (621) max	28 (193)	32	B80, max
Half-hard[E]	85 (586) min	55 (379)	12	B75 to B97
Full hard[F]	110 (758) min	90 (621)	3	B95 to C27
Nickel-chromium-iron alloy				
UNS N06600:				
Annealed[DG]	80 (552) to 110 (758)	35 (241)	30	B92, max
Half-hard[E]	105 (724) min	55 (379)	13	B90 to B98
Full-hard[F]	130 (896) min	105 (724)	4	C19 to C34
UNS N06601:				
Annealed[D,G]	80 (552) to 110 (758)	30 (207)	30	B92 max
Half-hard[E]	105 (724) min	55 (379)	13	B90 to B98
Full-hard[F]	130 (896) min	105 (724)	4	C19 to C34
UNS N06690:				
Annealed[D,G]	85 (586) to 115 (793)	35 (241)	30	B92 max
Half-hard[E]	105 (724) min	55 (379)	13	B90 to B98
Full-hard[F]	130 (896) min	105 (724)	4	C19 to C34
Nickel-iron chromium alloy				
UNS N08800:				
Annealed[DG]	75 (517) to 100 (689)	30 (207)	30	B95, max
Half-hard[E]	105 (724)	60 (414)	13	B93 to C26
Full hard[F]	130 (896)	105 (724)	4	C24 to C38
Nickel-iron chromium-molybdenum-copper alloy				
UNS N08825:				
Annealed[DG]	85 (586) to 115 (793)	35 (241)	30	B90 max
Half-hard[E]	105 (724) min	75 (517)	15	B90 to C25
Full-hard[F]	125 (862) min	100 (689)	5	C25 to C35

[A] Not applicable to outside diameters under ⅛ in. (3.2 mm) and to wall thicknesses under 0.015 in. (0.38 mm).
[B] See 12.3.
[C] Hardness values, indicative of tensile strength, are shown for information only. All tests are subject to confirmation by tension tests. For hardness conversions, see Hardness Conversion Tables E140.
[D] This condition is sometimes designated as “No. 1 Temper.”
[E] This condition is sometimes designated as “No. 2 Temper.”
[F] This condition is sometimes designated as “No. 3 Temper.”
[G] The minimum tensile strength value applies only to tubing in straight lengths.

TABLE X2.2 Permissible Variations for Small Diameter and Light Wall Tube (Converter Sizes)

NOTE 1—*Ovality, Normal Wall Tube:*
As-Drawn (No. 2 and 3) Tempers—Ovality will be held within the outside diameter tolerances shown in the table.
Annealed (No. 1) Temper—Ovality will be held within 2 % of the theoretical average outside diameter.

NOTE 2—*Ovality Light Wall Tube:*
As-Drawn (No. 2 and 3) Tempers—Ovality will be held within 2 % of the theoretical average outside diameter.
Annealed (No. 1) Temper—Ovality will be held within 3 % of the theoretical average outside diameter.

NOTE 3—*Wall Tolerances, Light Wall Tube*—The plus and minus wall tolerance shown in the table shall apply down to and including 0.005 in. (0.13 mm) in wall thickness. For wall thicknesses less than 0.005 in. the tolerance shall be plus and minus 0.0005 in.

NOTE 4—Random Lengths:
(a) Where nominal random lengths on tubing ⅛ in. and larger in outside diameter are specified, a length tolerance of plus and minus 3½ ft (1.1 m) applies to the nominal length. This is a total spread of 7 ft. (2.1 m).
(b) Random lengths in sizes ⅛ in. (3.2 mm) and larger in outside diameter shall be subject to a length range from 5 to 24 ft (1.5 to 7.3 m). Long random lengths are subject to a range from 15 to 22 ft (4.6 to 6.7 m).
(c) Random lengths in sizes up to, but not including, ⅛ in. in outside diameter, and fragile light wall tubes over this outside diameter are subject to the length range from 1 to 15 ft (0.3 to 4.6 m).

NOTE 5—*Cut Lengths*—Tolerances on cut lengths shall be as follows:

NOTE 6—*Straightness*—Round tubing is subject to a straightness tolerance of one part in 600 (equivalent to a depth of arc of 0.030 in. (0.76 mm) in any 3 ft (0.9 m) of length).

NOTE 7—*Eccentricity*—Eccentricity (as defined in Table 4, Note 2) shall be limited to plus or minus 10 % of the specified wall or calculated average wall.

NOTE 8—When specified, the tolerance spread may be applied as desired. However, when not specified the tolerances shown below will apply. It should be noted that inside diameter tolerances are based upon the outside diameter range.

Length, ft	Tube Size, in.	Permissible Variations, in.	
		Over	Under
U.S. Customary Units			
Under 1	Up to 1.250, incl	1/32	0
1 to 4, incl	Up to 1.250, incl	1/16	0
Over 4 to 10, incl	Up to 1.250, incl	3/32	0
Over 10	Up to 1.250, incl	3/16	0
Metric Units			
Length, m	Tube Size, mm	Permissible Variations, mm	
		Over	Under
Under 0.3	Up to 31.75, incl	0.794	0
0.3 to 1.2, incl	Up to 31.75, incl	1.59	0
1.2 to 3.0, incl	Up to 31.75, incl	2.38	0
Over 3.0	Up to 31.75, incl	4.76	0

Specified Outside Diameter, in.	Outside Diameter, in.		Inside Diameter, in.		Wall Thickness,%	
	+	–	+	–	+	–
U.S. Customary Units						
Under 3/32	0.002	0	0	0.002	10	10
to 3/16 (0.1875), excl	0.003	0	0	0.003	10	10
3/16 to ½ (0.500), excl	0.004	0	0	0.004	10	10
½ to 1¼ (1.250), incl	0.005	0	0	0.005	10	10
Millimetres						
Under 2.38	0.051	0	0	0.051	10	10
2.38 to 4.76, excl	0.076	0	0	0.076	10	10
4.76 to 12.70, excl	0.102	0	0	0.102	10	10
12.70 to 31.8, incl	0.127	0	0	0.127	10	10

SUMMARY OF CHANGES

Committee B02 has identified the location of selected changes to this standard since the last issue (B163 – 19) that may impact the use of this standard. (Approved April 1, 2022.)

(1) Table 1: Changed "columbium (Nb)" to "niobium" and added footnote stating Cb and Nb are interchangeable names for the same element; revised Al and Ti minimum for N08811; added max phosphorus to N08800, N08810, and N08811.