Designation: A 511 – 04

Standard Specification for Seamless Stainless Steel Mechanical Tubing[1]

This standard is issued under the fixed designation A 511; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

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

1. Scope*

1.1 This specification covers seamless stainless tubing for use in mechanical applications where corrosion-resistant or high-temperature strength is needed. The grades covered are listed in Table 1 and Table 2.

1.2 This specification covers seamless cold-finished mechanical tubing and seamless hot-finished mechanical tubing in sizes up to 12¾ in. (313.8 mm) in outside diameter (for round tubing) with wall thicknesses as required.

1.3 Tubes shall be furnished in one of the following shapes, as specified by the purchaser: round, square, rectangular, or special.

1.4 Optional supplementary requirements are provided and when desired, shall be stated in the order.

1.5 The values stated in inch-pound units are to be regarded as the standard.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products

A 1016/A 1016M Specification for General Requirements for Ferritic Alloy Steel, Austenitic Alloy Steel, and Stainless Steel Tubes

E 59 Practice for Sampling Steel and Iron for Determination of Chemical Composition

2.2 *Military Standards:*

MIL-STD-129 Marking for Shipment and Storage[3]

MIL-STD-163 Steel Mill Products Preparation for Shipment and Storage[3]

2.3 *Federal Standard:*

Fed. Std. No. 123 Marking for Shipments (Civil Agencies)[3]

3. Ordering Information

3.1 Orders for material under this specification should include the following as required to describe the desired material adequately:

3.1.1 Quantity (feet, mass, or number of pieces),

3.1.2 Name of material (seamless stainless steel mechanical tubing),

3.1.3 Form (round, square, rectangular, special, see Section 1),

3.1.4 Dimensions (round, outside diameter and wall thickness, see Section 9; square and rectangular, outside dimensions and wall thickness, see Section 10; other, specify),

3.1.5 Length (specific or random, see 9.3),

3.1.6 Manufacture (cold- or hot-finished, see 4.5),

3.1.7 Grade (Section 6),

3.1.8 Condition (annealed, as cold worked, or with special heat treatment, controlled microstructural characteristics, or other condition as required, see Section 5),

3.1.9 Surface finish (special pickling, shot blasting, or polishing, as required, see Supplementary Requirement S5),

3.1.10 Specification designation,

3.1.11 Report of Chemical Analysis, if required (Sections 7 and 8),

3.1.12 Individual supplementary requirements, if required,

3.1.13 End use,

3.1.14 Packaging,

3.1.15 Special marking (see 15.2),

3.1.16 Special packing (see 16.2), and

3.1.17 Special requirements.

4. Materials and Manufacture

4.1 The steel may be made by any process.

4.2 If a specific type of melting is required by the purchaser, it shall be as stated on the purchase order.

4.3 The primary melting may incorporate separate degassing or refining and may be followed by secondary melting, such as electroslag remelting or vacuum-arc remelting. If secondary melting is employed, the heat shall be defined as all of the ingots remelted from a single primary heat.

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[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys, and is the direct responsibility of Subcommittee A01.10 on Tubing.

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[2] 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.

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

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

TABLE 1 Chemical Requirements of Austenitic Stainless Steels

Grade	Composition, %										
	Carbon	Manganese, max	Phosphorus, max	Sulfur, max	Silicon, max	Nickel	Chromium	Molybdenum	Titanium	Columbium plus Tantalum	Selenium
MT 302	0.08 to 0.20	2.00	0.040	0.030	1.00	8.0–10.0	17.0–19.0	...	...	...	...
MT 303Se	0.15 max	2.00	0.040	0.040	1.00	8.0–11.0	17.0–19.0	...	...	...	0.12–0.2
MT 304	0.08 max	2.00	0.040	0.030	1.00	8.0–11.0	18.0–20.0	...	...	...	...
MT 304L	0.035 max[A]	2.00	0.040	0.030	1.00	8.0–13.0	18.0–20.0	...	...	...	...
MT 305	0.12	2.00	0.040	0.030	1.00	10.0–13.0	17.0–19.0	...	...	...	...
MT 309S	0.08 max	2.00	0.040	0.030	1.00	12.0–15.0	22.0–24.0	...	...	...	...
MT 310S	0.08 max	2.00	0.040	0.030	1.00	19.0–22.0	24.0–26.0	...	...	...	...
MT 316	0.08 max	2.00	0.040	0.030	1.00	11.0–14.0	16.0–18.0	2.0–3.0	...	...	...
MT 316L	0.035 max[A]	2.00	0.040	0.030	1.00	10.0–15.0	16.0–18.0	2.0–3.0	...	...	...
MT 317	0.08 max	2.00	0.040	0.030	1.00	11.0–14.0	18.0–20.0	3.0–4.0	...	...	...
MT 321	0.08 max	2.00	0.040	0.030	1.00	9.0–13.0	17.0–20.0	...	[B]	...	...
MT 347	0.08 max	2.00	0.040	0.030	1.00	9.0–13.0	17.0–20.0	...	...	[C]	...

[A]For small diameter or thin wall tubing or both, where many drawing passes are required, a maximum of 0.040 % carbon is necessary in grades MT-304L and MT-316L. Small outside diameter tubes are defined as those under a 0.500 in. outside diameter and light-wall tubes as those under an 0.049 in. average wall thickness (0.044 in. min wall thickness).

[B]The titanium content shall be not less than five times the carbon content and not more than 0.60 %.

[C]The columbium plus tantalum content shall be not less than ten times the carbon content and not more than 1.00 %.

TABLE 2 Chemical Requirements of Ferritic and Martensitic Stainless Steels

Grade	Composition, %											
	Carbon, max	Manganese, max	Phosphorus, max	Sulfur, max	Silicon, max	Nickel	Chromium	Molybdenum	Aluminum	Copper	Nitrogen	Selenium
Martensitic												
MT 403	0.15	1.00	0.040	0.030	0.50	0.50 max	11.5–13.0	0.60 max				
MT 410	0.15	1.00	0.040	0.030	1.00	0.50 max	11.5–13.5	...	...	...	...	...
MT 414	0.15	1.00	0.040	0.030	1.00	1.25–2.50	11.5–13.5	...	...	...	...	...
MT 416Se	0.15	1.25	0.060	0.060	1.00	0.50 max	12.0–14.0	...	...	...	...	0.12–0.20
MT 431	0.20	1.00	0.040	0.030	1.00	1.25–2.50	15.0–17.0	...	...	...	...	...
MT 440A	0.60 to 0.75	1.00	0.040	0.030	1.00	...	16.0–18.0	0.75 max	...	...	...	...
Ferritic												
MT 405	0.08	1.00	0.040	0.030	1.00	0.50 max	11.5–14.5	...	0.10–0.30	...	...	...
MT 429	0.12	1.00	0.040	0.030	1.00	0.50 max	14.0–16.0	...	...	...	...	...
MT 430	0.12	1.00	0.040	0.030	1.00	0.50 max	16.0–18.0	...	...	...	...	...
MT 443	0.20	1.00	0.040	0.030	1.00	0.50 max	18.0–23.0	...	...	0.90–1.25	...	...
MT 446–1	0.20	1.50	0.040	0.030	1.00	0.50 max	23.0–30.0	...	...	...	0.25 max	...
MT 446–2[A]	0.12	1.50	0.040	0.030	1.00	0.50 max	23.0–30.0	...	...	...	0.25 max	...
29-4	0.010	0.30	0.025	0.020	0.20	0.15 max	28.0–30.0	3.5–4.2	...	0.15 max	0.020 max	...
29-4-2	0.010	0.30	0.025	0.020	0.20	2.0–2.5	28.0–30.0	3.5–4.2	...	0.15 max	0.020 max[B]	...

[A]MT446-2 is a lower carbon version of MT446-1, that has a lower tensile strength but improved ductility and toughness.

[B]Carbon plus nitrogen = 0.025 max %.

4.4 Steel may be cast in ingots or may be strand cast. When steel of different grades is sequentially strand cast, identification of the resultant transition material is required. The producer shall remove the transition material by an established procedure that positively separates the grades.

4.5 The tubes shall be made by a seamless process and by either cold working or hot working as specified. Seamless steel tubing is a tubular product made without a welded seam. It is usually manufactured by hot working steel and then cold finishing the hot-worked tubing to produce the desired shape, dimensions, and properties.

5. Condition

5.1 Round seamless stainless mechanical tubing is generally supplied in the cold-worked and annealed condition (see 5.2 through 5.4). Square, rectangular, or other shapes of tubing are generally supplied annealed prior to final cold shaping. If some other condition is desired, details shall be included in the order.

5.2 The thermal treatment for ferritic and martensitic steels shall be performed by a method and at a temperature selected by the manufacturer unless otherwise specified by the purchaser.

5.3 Unless otherwise specified, all austenitic tubes shall be furnished in the annealed condition. The anneal shall consist of heating the material to a minimum temperature of 1900°F (1040°C) and quenching in water or rapidly cooling by other means. Alternatively, immediately following hot forming while the temperature of the tubes is not less than the specified minimum solution treatment temperature, tubes may be individually quenched in water or rapidly cooled by other means. This anneal shall precede final cold work, when cold-worked tempers are required.

5.4 If any controlled microstructural characteristics are required, these shall be specified so as to be a guide to the most suitable heat treatment.

6. Chemical Composition

6.1 The steel shall conform to the requirements as to chemical composition prescribed in Table 1 or Table 2. Other grades are available.

7. Heat Analysis

7.1 An analysis of each heat of steel shall be made by the steel manufacturer to determine the percentages of the elements specified. If secondary melting processes are employed, the heat analysis shall be obtained from one remelted ingot or the product of one remelted ingot of each primary melt. The chemical composition thus determined, or that determined from a product analysis made by the tubular product manufacturer, shall be reported to the purchaser or the purchaser's representative and shall conform to the requirements specified. When requested in the order or contract, a report of this analysis shall be furnished to the purchaser.

8. Product Analysis

8.1 An analysis of either one billet or one tube shall be made for each heat of steel. Samples for chemical analysis, except spectrochemical analysis, shall be taken in accordance with Method E 59. The chemical composition thus determined shall conform to the requirements specified in Section 6.

8.2 If the original test for product analysis fails, retests of two additional billets or tubes shall be made. Both retests, for the elements in question, shall meet the requirements of the specification, otherwise all remaining material in the heat or lot shall be rejected or, at the option of the producer, each billet or tube may be individually tested for acceptance. Billets or tubes which do not meet the requirements of this specification shall be rejected.

9. Permissible Variations in Dimensions of Round Tubing

9.1 *Diameter and Wall Thickness (Cold Finished)*—Variations in outside diameter and wall thickness shall not exceed the amounts prescribed in Table 3.

9.2 *Diameter and Wall Thickness (Hot Finished)*—Variations in outside diameter and wall thickness shall not exceed the amounts prescribed in Table 4.

9.3 *Lengths (Cold Finished or Hot Finished)*—Mechanical tubing is commonly furnished in mill lengths 5 ft (1.5 m) and over. When random lengths are ordered, tube lengths may vary by an amount up to 7 ft (2.1 m). Definite cut lengths are furnished, when specified, to the length tolerances shown in Table 3 or Table 4. For tubing ordered in multiple lengths, it is common practice to allow a definite amount over for each multiple for the purchaser's cutting operations. This amount depends on the type of purchaser's cutting and varies with differing wall thickness. The cutting allowance should be specified on the purchase order. When it is not specified, tubing is customarily supplied with the following allowance for each multiple:

Wall Thickness, in. (mm)	Excess Length per Multiple, in. (mm)
Up to ⅛ (3.2)	⅛ (3.2)
Over ⅛ to ½ (3.2 to 12.7)	3⁄16 (4.8)
Over ½ (12.7)	¼ (6.4)

9.4 *Straightness Tolerances (Cold Finished or Hot Finished)*—The deviation from straightness shall not exceed the amounts shown in Table 5 when measured with a 3-ft (0.9-m) straightedge and feeler gage. If determined by the dial

TABLE 3 Permissible Variations in Outside Diameter, Ovality, Wall Thickness, and Cut-Length Variations (Cold-Finished Round Tubing)[A]

Outside Diameter, in.	Outside Diameter, Tolerance,[B] in. Over and Under	Ovality,[B] Double Outside Diameter Tolerance when wall is:	Wall Thickness in %[C,D]		Permissible Variations in Cut Length, in.[E]	
			Over	Under	Over	Under
Under ½	0.005	less than 0.015 in.	15	15	⅛	0
½ to 1½ , excl	0.005	less than 0.065 in.	10	10	⅛	0
1½ to 3½ , excl	0.010	less than 0.095 in.	10	10	3⁄16	0
3½ to 5½ , excl	0.015	less than 0.150 in.	10	10	3⁄16	0
5½ to 8, excl	0.030	less than 0.240 in.	10	10	3⁄16	0
8 to 8⅝ , excl	0.045	less than 0.300 in.	10	10	3⁄16	0
8⅝ to 12¾ , incl	0.062	less than 0.350 in.	10	10	3⁄16	0

[A] Tolerances of tubes produced by the rod or bar mandrel process and which have an inside diameter under ½ in. (12.7 mm) (or an inside diameter under ⅝ in. (15.8 mm) when the wall thickness is more than 20 % of the outside diameter) are as shown in this table, except that wall thickness tolerances are 10 % over and under the specified wall thickness.

[B] For ovality values, the tolerance for average outside diameter at any one cross section does not exceed the outside diameter tolerance value for the applicable outside diameter.

[C] Many tubes with wall thicknesses more than 25 % of outside diameter or with wall thicknesses over 1¼ in., (31.7 mm) or weighing more than 90 lb/ft, are difficult to draw over a mandrel. Therefore, the wall thickness can vary 12½ % over and under that specified. Also see Footnote (*B*).

[D] For those tubes with inside diameter under ½ in. (12.7 mm) (or under ⅝ in. (15.8 mm) when the wall thickness is more than 20 % of the outside diameter) which are not commonly drawn over a mandrel, Footnote (*A*) is not applicable. Therefore, the wall thickness can vary 15 % over and under that specified, and the inside diameter is governed by both the outside diameter and wall thickness tolerances.

[E] These tolerances apply to cut lengths up to and including 24 ft. (7.3 m). For lengths over 24 ft, an additional over tolerance of ⅛ in. (3.1 mm) for each 10 ft (3 m) or fraction thereof shall be permissible, up to a maximum tolerance of ½ in. (12.7 mm).

TABLE 4 Permissible Variations in Outside Diameter, Wall Thickness, and Cut-Length Variations (Hot-Finished Round Tubing)

Specified Size, Outside Diameter, in.	Ratio of Wall Thickness to Outside Diameter	Outside Diameter and Wall Thickness Tolerances										Permissible Variations in Cut Length, in.[A]	
		Outside Diameter, in.		Wall Thickness, %									
				0.109 in. and under		0.109 to 0.172 in., incl		Over 0.172 to 0.203 in., incl		Over 0.203 in.			
		Over	Under	Over	Under	Over	Under	Over	Under	Over	Under		
Under 3	all wall thicknesses	0.023	0.023	16.5	16.5	15	15	14	14	12.5	12.5	3/16	0
3 to 5½ , excl	all wall thicknesses	0.031	0.031	16.5	16.5	15	15	14	14	12.5	12.5	3/16	0
5½ to 8, excl	all wall thicknesses	0.047	0.047	...	...	...	...	14	14	12.5	12.5	3/16	0
8 to 10¾ , excl	5 % and over	0.047	0.047	...	...	...	...	...	...	12.5	12.5	3/16	0
10¾ to 12¾ , incl	under 5 %	0.063	0.063	...	...	...	...	...	...	12.5	12.5	3/16	0

[A] These tolerances apply to cut lengths up to and including 24 ft (7.3 m). For lengths over 24 ft, an additional over tolerance of ⅛ in. (3.1 mm) for each 10 ft (3 m) or faction thereof shall be permissible, up to a maximum tolerance of ½ in. (12.7 mm).

TABLE 5 5 Straightness Tolerances (Cold-/Finished or Hot-/Finished Round Tubing)[A]

Size Limits	Max Curvature in any 3 ft, in.	Max Curvature in Total Lengths, in.	Max Curvature for Lengths under 3 ft
OD 5 in. and smaller. Wall thickness, over 3 % of OD but not over 0.5 in.	0.030	0.030 × [(Number of feet of length)/3]	Ratio of 0.010 in./ft
OD over 5 in. to 8 in., incl. Wall thickness, over 4 % of OD but not over 0.75 in.	0.045	0.045 × [(Number of feet of length)/3]	Ratio of 0.015 in./ft
OD over 8 in. to 12¾ , incl. Wall thickness, over 4 % of OD but not over 1 in.	0.060	0.060 × [(Number of feet of length)/3]	Ratio of 0.020 in./ft

[A] The usual procedure for measuring straightness is by means of a 3-ft (0.9 m) straight edge and feeler gage. If determined by the dial indicator method, the values obtained will be approximately twice those determined by the straightedge feeler gage method.

indicator method, the values obtained will be approximately twice those determined by the straightedge feeler gage method.

10. Permissible Variations in Dimensions of Square and Rectangular Tubing

10.1 Square and rectangular seamless stainless mechanical tubing is supplied as cold worked unless otherwise specified. For this tubing, variations in dimensions from those specified shall not exceed the amounts prescribed in Table 6, Table 7, Table 8, and Table 9.

10.2 The squareness of sides is commonly determined by one of the following methods.

TABLE 6 Permissible Variations in Outside Dimensions for Square and Rectangular Seamless Mechanical Tubing[AB]

Largest Outside Dimension Across Flats, in.	Tolerances, Outside Dimension Seamless Mechanical Tubing Plus and Minus, in.	
	For Wall Thickness, Given, in.	Tolerance for Outside Dimension (Including Convexity or Concavity) Plus and Minus, in.
To ¾ , incl	0.065 and lighter	0.015
To ¾ , incl	over 0.065	0.010
Over ¾ to 1¼ , incl	all thicknesses	0.015
Over 1¼ to 2½ , incl	all thicknesses	0.020
Over 2½ to 3½ , incl	0.065 and lighter	0.030
Over 2½ to 3½ , incl	over 0.065	0.025
Over 3½ to 5½ , incl	all thicknesses	0.030
Over 5½ to 7½ , incl	all thicknesses	1 %

[A] The wall thickness tolerance is plus and minus 10 % of nominal wall thickness.
[B] The straightness tolerance is 0.075 in. 3 ft. using a 3-ft straight edge and feeler gage.

TABLE 7 Permissible Variations in Radii of Corners for Square and Rectangular Seamless Mechanical Tubing

Wall Thickness, in.	Maximum Radii of Corners, in.
Over 0.020 to 0.049, incl	3/32
Over 0.049 to 0.065, incl	⅛
Over 0.065 to 0.083, incl	9/64
Over 0.083 to 0.095, incl	3/16
Over 0.095 to 0.109, incl	13/64
Over 0.109 to 0.134, incl	7/32
Over 0.134 to 0.156, incl	¼
Over 0.156 to 0.188, incl	9/32
Over 0.188 to 0.250, incl	11/32
Over 0.250 to 0.313, incl	7/16
Over 0.313 to 0.375, incl	½
Over 0.375 to 0.500, incl	11/16
Over 0.500 to 0.625, incl	27/32

TABLE 8 Twist Tolerances for Square and Rectangular Tubing

Largest Size	Maximum Twist in 3 ft, in.
Under ½	0.050
½ to 1½ , incl	0.075
Over 1½ to 2½ , incl	0.095
Over 2½	0.125

10.2.1 A square, with two adjustable contact points on each arm, is placed on two sides. A fixed feeler gage is then used to measure the maximum distance between the free contact point and the surface of the tubing.

10.2.2 A square, equipped with a direct reading vernier, may be used to determine the angular deviation which, in turn, may be related to distance in inches.

TABLE 9 Length Tolerances for Square and Rectangular Tubing

Length tolerance on exact lengths of tubing (all types)	+⅜ , − 0

10.3 The squareness of sides varies in accordance with the following equation:

$$\pm b = c \times 0.006$$

where:
b = tolerance for out-of-square, and
c = length of longest side.

Example: Rectangular tubes 2 by 1 may have sides fail to be 90° to each other by ±0.012 in.

10.4 The twist in square and rectangular tubing may be measured by holding one end of the tubing on a surface plate and noting the height above the surface plate of either corner of the opposite end of the same side. Twist may also be measured by the use of a beveled protractor, equipped with a level, and noting the angular deviation on opposite ends, or at any point throughout the length.

11. Workmanship, Finish, and Appearance

11.1 Finished tubes shall have smooth ends free of burrs. They shall be free of injurious defects and shall have a workmanlike finish. Surface imperfections such as handling marks, straightening marks, light mandrel and die marks, shallow pits and scale pattern, will not be considered as injurious defects, provided the imperfections are removable within the wall tolerance unless a machining allowance has been specified. When a machining allowance has been specified, the imperfections shall be removable within the machining allowances. The removal of surface imperfections is not required.

11.2 Tubes shall be free of scale and suitable for inspection.

12. Machining Allowances of Round Tubing

12.1 Clean-up or machining allowances for stainless steel round mechanical tubing are shown in Table 10. For the method of calculating the tube size required to clean up in machining to a particular finished part, see Appendix X1.

13. Rejection

13.1 Tubing that fails to meet the requirements of this specification shall be set aside and the manufacturer notified.

14. Coating

14.1 Stainless tubing is commonly shipped without protective coating. If special protection is needed, details shall be shown on the order.

TABLE 10 Cleanup or Machining Allowances for Round Tubing[A]

For Machined Parts Size, Outside Diameter, in.	Machining Allowances on Diameter, in.	
	Outside Diameter	Inside Diameter
Less than 3/32	0.008	0.008
3/32 to 3/16 , excl	0.012	0.012
3/16 to ½ , excl	0.015	0.015
½ to 1½ , excl	0.020	0.020
1½ to 3, excl	0.040	0.040
3 to 5½ , excl	0.060	0.060
5½ to 8,[B] excl	0.080	0.080

[A]The allowances in this table are nominal allowances which have been satisfactorily used for many applications but are not necessarily adequate for all tubular products and methods of machining. For example, when magnetic particle inspection or aircraft quality requirements are involved, it is customary to use greater allowances than those shown in the foregoing table.

[B]For machining allowances for sizes 8 in. and over the producer should be consulted.

15. Product and Package Marking

15.1 *Civilian Procurement*—Each box, bundle, lift, or piece shall be identified by a tag or stencil with the manufacturer's name or brand, specified size, purchaser's order number, grade, and this specification number.

15.2 *Government Procurement*—When specified in the contract or order, and for direct procurement by or direct shipment to the Government, marking for shipment, in addition to requirements specified in the contract or order, shall be in accordance with MIL-STD-129 for Military agencies and in accordance with Fed. Std. No. 123 for civil agencies.

16. Packaging

16.1 *Civilian Procurement*—On tubing 0.065 in. (1.65 mm) wall and under, the manufacturer will, at his option, box, crate, carton, package in secure lifts, or bundle to ensure safe delivery. Tubing over 0.065 in. (1.65 mm) wall will normally be shipped loose, bundled, or in secured lifts. Special packaging requiring extra operations other than those normally used by the manufacturer must be specified on the order.

16.2 *Government Procurement*—When specified in the contract or order, and for direct procurement by or direct shipment to the Government when Level A is specified, preservation, packaging, and packing shall be in accordance with the Level A requirements of MIL-STD-163.

17. Keywords

17.1 austenitic stainless steel; mechanical tubing; seamless steel tube; stainless steel tube; steel tube

SUPPLEMENTARY REQUIREMENTS

These requirements shall not be considered unless specified in the order and the necessary tests shall be made at the mill. Mechanical tests shall be performed in accordance with Test Methods and Definitions A 370.

S1. Hardness Test

S1.1 The tubes shall conform to the hardness limits specified in Table S1.1, unless cold worked tempers or special thermal treatments are ordered, in which case the manufacturer should be consulted for expected hardness values. S1.2 When specified, the hardness test shall be performed on a specimen from one tube from each lot of 100 tubes or fraction thereof from each heat of steel.

S2. Tension Test

S2.1 Unless cold-worked tempers or special thermal treatments are ordered, the tubes shall conform to the tensile requirements shown in Table S2.1. When cold-worked tempers or special thermal treatments are ordered, the tube manufacturer should be consulted.

S2.2 When the tension test is specified, one test shall be performed on a specimen from one tube taken from each lot of 100 tubes or fraction thereof from each heat of steel.

S2.3 The yield strength corresponding to a permanent offset of 0.2 % of the gage length of the specimen or to a total extension of 0.5 % of the gage length under load shall be determined.

S3. Nondestructive Tests

S3.1 Various types of nondestructive ultrasonic or electromagnetic tests are available. When any such test is required, the test to be used and the inspection limits required shall be specified. Generally, for ultrasonic test, the most restrictive limit which may be specified is 3 % of the wall thickness or 0.004 in. (0.10 mm) (whichever is greater). For a description and inspection table of another type of non-destructive electric test, see the section on Nondestructive Electric Test in Specification A 1016/A 1016M.

TABLE S1.1 Hardness Requirements for Round Tubing in Annealed Condition[A]

Grade	Brinell Hardness Number, max	Rockwell Hardness Number, B Scale, max
All austenitic	192	90
MT 403	207	95
MT 405	207	95
MT 410	207	95
MT 414	235	99
MT 416 Se	230	97
MT 429/MT 430	190	90
MT 431	260	. . .
MT 440 A	215	95
MT 443	207	95
MT 446	207	95
29-4	207	95
29-4-2	207	95

[A]Not applicable when cold-worked tempers or special thermal treatment is ordered.

TABLE S2.1 Tensile Requirements for Round Tubing in Annealed Condition[A]

Grade	Tensile Strength, min, ksi (MPa)	Yield Strength min, ksi (MPa)	Elongation[B] in 2 in., or 50 mm min., %
All austenitic steels[C]	75 (517)	30 (207)	35
MT 403	60 (414)	30 (207)	20
MT 405	60 (414)	30 (207)	20
MT 410	60 (414)	30 (207)	20
MT 414	100 (689)	65 (448)	15
MT 416 Se	60 (414)	35 (241)	20
MT 429/MT 430	60 (414)	35 (241)	20
MT 431	105 (724)	90 (621)	20
MT 440 A	95 (655)	55 (379)	15
MT 443	70 (483)	40 (276)	20
MT 446–1	70 (483)	40 (276)	18
MT 446–2	65 (448)	40 (276)	20
29-4	70 (483)	55 (379)	20
29-4-2	70 (483)	55 (379)	20

[A]Not applicable to tubes under a ⅛ in. (3.1 mm) outside diameter or less than 0.015 in. (0.38 mm) in wall thickness, or both. The tensile properties of such small diameter or thin wall tubes are a matter of agreement between manufacturer and purchaser. For tubing having an outside diameter of ⅜ in. or under, the gage length shall be four times the outside diameter in order to obtain elongation values comparable to the larger sizes (Test Methods and Definitions A 370).

[B]For longitudinal strip tests, the width of the gage section shall be 1 in. (25.4 mm). A deduction of 1.0 percentage points for ferritic and martenistic grades shall be permitted from the basic minimum elongation for each 1/32 in. (0.8 mm) decrease in wall thickness under 5/16 in. (7.9 mm). The calculated elongation requirement shall be rounded to the nearest whole number.

[C]When grades TP304L, and TP316L are required to pass special corrosion tests, these minimum values for tensile strength and yield strength may not be met.

S4. Hardenability

S4.1 Any requirement for special hardenability tests and test limits for martensitic stainless grades shall be detailed on the order. Hardenability requirements are not applicable to austenitic or ferritic grades.

S5. Surface Finish

S5.1 Any special pickling, shortblasting, or polishing requirements shall be detailed in the order.

S6. Certification for Government Orders

S6.1 A producer's or supplier's certification shall be furnished to the Government that the material was manufactured, sampled, tested, and inspected in accordance with this specification and has been found to meet the requirements. This certificate shall include a report of heat analysis (product analysis when requested in the purchase order), and when specified in the purchase order or contract, a report of test results shall be furnished.

S7. Rejection Provisions for Government Orders

S7.1 Each length of tubing received from the manufacturer may be inspected by the purchaser and, if it does not meet the requirements of the specification based on the inspection and

test method as outlined in the specification, the tube may be rejected and the manufacturer shall be notified. Disposition of rejected tubing shall be a matter of agreement between the manufacturer and the purchaser.

S7.2 Material that fails in any of the forming operations or in the process of installation and is found to be defective shall be set aside and the manufacturer shall be notified for mutual evaluation of the material's suitability. Disposition of such materials shall be a matter for agreement.

APPENDIX

(Nonmandatory Information)

X1. MACHINING ALLOWANCES FOR CARBON, ALLOY AND STAINLESS STEEL SEAMLESS MECHANICAL TUBING

X1.1 Seamless mechanical tubing is produced either hot finished or cold worked. Hot finished tubes are specified to outside diameter and wall thickness. Cold-worked tubing is specified to two of the three dimensions: outside diameter, inside diameter, and wall thickness.

X1.2 There are two basic methods employed in machining such tubing: (*1*) by machining true to the outside diameter of the tube and (*2*) by machining true to the inside diameter of the tube.

X1.3 For the purpose of determining tube size dimensions with sufficient allowances for machining, the following four steps are customarily used.

X1.4 Step 1—Step 1 is used to determine the maximum tube outside diameter.

X1.4.1 *Machined Outside Diameter*—Purchaser's maximum blueprint (finish-machine) size including plus machine tolerance.

X1.4.2 *Cleanup Allowance*—Sufficient allowance should be made to remove surface imperfections.

X1.4.3 *Decarburization*— Decarburization is not important in most stainless grades but is an important factor on the higher carbon grades or steel including Type 440A. Decarburization limits are shown in various specifications. For example, the decarburization limits for aircraft steels are shown in AMS and appropriate government specifications. Decarburization is generally expressed as depth and, therefore must be doubled to provide for removal from the surface.

X1.4.4 *Camber*—When the machined dimension extends more than 3 in. (76.2 mm) from the chuck or other holding mechanism, the possibility that the tube will be out-of-straight must be taken into consideration. An allowance is made equal to four times the straightness tolerance shown in Table 5, for the machined length when chucked at only one end and equal to twice the straightness tolerance if supported at both ends.

X1.4.5 *Outside Diameter Tolerance*—If machined true to the outside diameter, add the complete spread of tolerance (for example, for specified outside diameter of 3 to 5½ in. (76.2 to 139.7 mm), exclusive, plus and minus 0.031 in. or 0.062 in.). If machined true to the inside diameter, outside diameter tolerances are not used in this step. Cold-worked tolerances are shown in Table 3. Hot-finished tolerances are shown in Table 4. The calculated maximum outside diameter is obtained by adding X1.4.1 through X1.4.5.

X1.5 Step 2—Step 2 is used to determine the minimum inside diameter.

X1.5.1 *Machined Inside Diameter*

Purchaser's minimum blueprint (finished-machine) size including machining tolerance.

X1.5.2 *Cleanup Allowance*—Sufficient allowance should be made to remove surface imperfections.

X1.5.3 *Decarburization*— Decarburization is an important factor on the higher carbon grades of steel including Type 440A. Decarburization limits are shown in various specifications. For example, the decarburization limits for aircraft are shown in AMS and appropriate government specifications. Decarburization is generally expressed as depth and therefore must be doubled to provide for removal from the surface.

X1.5.4 *Camber*—Refer to X1.4.4.

X1.5.5 *Inside Diameter Tolerances*—If machined true to the outside diameter, inside diameter tolerances are not used in this step. If machined true to the inside diameter, subtract the complete spread of tolerance (plus and minus). Cold-worked tolerances are shown in Table 5. Hot-finished tolerances (use outside diameter tolerances for inside diameter for calculating purposes) are shown in Table 4. The calculated minimum is obtained by subtracting the sum of X1.5.2 through X1.5.5 from X1.5.1.

X1.6 Step 3—Step 3 is used to determine the average wall thickness.

X1.6.1 One half the difference between the maximum outside diameter and the minimum inside diameter is considered to be the calculated minimum wall. From the calculated minimum wall, the average is obtained by dividing by 0.90 for cold-worked tubing or 0.875 for hot-finished tubing. This represents the wall tolerance of plus and minus 10 % for cold-worked tubing and plus and minus 12½ % for hot-finished tubing. The wall tolerances may be modified in special cases as covered by applicable tables.

X1.7 Step 4—Step 4 is used to determine cold-worked or hot-finished tube size when machined true to the outside diameter or machined true to the inside diameter.

X1.7.1 *Cold Worked Machined True to Outside Diameter*—Size obtained in Step 1 minus the over tolerance (shown in "Over" column in Table 3) gives the outside diameter to be specified. The wall thickness to be specified is that determined in Step 3.

X1.7.2 *Cold Worked Machined True to Inside Diameter*—Size obtained in Step 2 plus twice the calculated wall obtained in Step 3 gives the minimum outside diameter. To find the outside diameter to be specified, add the under part of the tolerance shown in the under outside diameter column in Table 3. The average wall thickness to be specified is that determined in Step 3. If necessary to specify to inside diameter and wall, the under tolerance for inside diameter (shown in Table 3) is added to the inside diameter obtained in Step 2.

X1.7.3 *Hot Finished Machined True to Outside Diameter*—From the size obtained in Step 1, subtract one-half the total tolerance (shown in Table 4) to find the outside diameter to be specified. The average wall thickness to be specified is that determined in Step 3.

X1.7.4 *Hot Finished Machined True to Inside Diameter*—The average outside diameter to be specified is obtained by adding the under part of the tolerance (shown in the under column of Table 4) to the minimum outside diameter, calculated by adding twice the average wall (from Step 3) to the minimum inside diameter (from Step 2).

SUMMARY OF CHANGES

Committee A01 has identified the location of selected changes to this specification since the last issue, A 511 – 96, that may impact the use of this specification. (Approved March 1, 2004)

(*1*) Replaced A 450/A 450M with A 1016/A 1016M in 2.1 and S3.1.