

SPECIFICATION FOR SEAMLESS AND WELDED TITANIUM AND TITANIUM ALLOY TUBES FOR CONDENSERS AND HEAT EXCHANGERS



SB-338



(Identical with ASTM Specification B338-17. For editions prior to 08a, certification and test reports are mandatory, and product marking shall also show ASME designation.)

Specification for Seamless and Welded Titanium and Titanium Alloy Tubes for Condensers and Heat Exchangers

1. Scope

1.1 This specification covers the requirements for 28 grades of titanium and titanium alloy tubing intended for surface condensers, evaporators, and heat exchangers, as follows:

- 1.1.1 *Grade 1*—UNS R50250. Unalloyed titanium,
- 1.1.2 *Grade 2*—UNS R50400. Unalloyed titanium,
 - 1.1.2.1 *Grade 2H*—UNS R50400. Unalloyed titanium (Grade 2 with 58 ksi (400 MPa) minimum UTS),
- 1.1.3 *Grade 3*—UNS R50550. Unalloyed titanium,
- 1.1.4 *Grade 7*—UNS R52400. Unalloyed titanium plus 0.12 to 0.25 % palladium,
 - 1.1.4.1 *Grade 7H*—UNS R52400. Unalloyed titanium plus 0.12 to 0.25 % palladium (Grade 7 with 58 ksi (400 MPa) minimum UTS),
- 1.1.5 *Grade 9*—UNS R56320. Titanium alloy (3 % aluminum, 2.5 % vanadium),
- 1.1.6 *Grade 11*—UNS R52250. Unalloyed titanium plus 0.12 to 0.25 % palladium,
- 1.1.7 *Grade 12*—UNS R53400. Titanium alloy (0.3 % molybdenum, 0.8 % nickel),
- 1.1.8 *Grade 13*—UNS R53413. Titanium alloy (0.5 % nickel, 0.05 % ruthenium),
- 1.1.9 *Grade 14*—UNS R53414. Titanium alloy (0.5 % nickel, 0.05 % ruthenium),
- 1.1.10 *Grade 15*—UNS R53415. Titanium alloy (0.5 % nickel, 0.05 % ruthenium),
- 1.1.11 *Grade 16*—UNS R52402. Unalloyed titanium plus 0.04 to 0.08 % palladium,
 - 1.1.11.1 *Grade 16H*—UNS R52402. Unalloyed titanium plus 0.04 to 0.08 % palladium (Grade 16 with 58 ksi (400 MPa) minimum UTS),

- 1.1.12 *Grade 17*—UNS R52252. Unalloyed titanium plus 0.04 to 0.08 % palladium,

- 1.1.13 *Grade 18*—UNS R56322. Titanium alloy (3 % aluminum, 2.5 % vanadium) plus 0.04 to 0.08 % palladium,

- 1.1.14 *Grade 26*—UNS R52404. Unalloyed titanium plus 0.08 to 0.14 % ruthenium,

- 1.1.14.1 *Grade 26H*—UNS R52404. Unalloyed titanium plus 0.08 to 0.14 % ruthenium (Grade 26 with 58 ksi (400 MPa) minimum UTS),

- 1.1.15 *Grade 27*—UNS R52254. Unalloyed titanium plus 0.08 to 0.14 % ruthenium,

- 1.1.16 *Grade 28*—UNS R56323. Titanium alloy (3 % aluminum, 2.5 % vanadium) plus 0.08 to 0.14 % ruthenium,

- 1.1.17 *Grade 30*—UNS R53530. Titanium alloy (0.3 % cobalt, 0.05 % palladium),

- 1.1.18 *Grade 31*—UNS R53532. Titanium alloy (0.3 % cobalt, 0.05 % palladium),

- 1.1.19 *Grade 33*—UNS R53442. Titanium alloy (0.4 % nickel, 0.015 % palladium, 0.025 % ruthenium, 0.15 % chromium),

- 1.1.20 *Grade 34*—UNS R53445. Titanium alloy (0.4 % nickel, 0.015 % palladium, 0.025 % ruthenium, 0.15 % chromium),

- 1.1.21 *Grade 35*—UNS R56340. Titanium alloy (4.5 % aluminum, 2 % molybdenum, 1.6 % vanadium, 0.5 % iron, 0.3 % silicon),

- 1.1.22 *Grade 36*—UNS R58450. Titanium alloy (45 % niobium),

- 1.1.23 *Grade 37*—UNS R52815. Titanium alloy (1.5 % aluminum),

- 1.1.24 *Grade 38*—UNS R54250. Titanium alloy (4 % aluminum, 2.5 % vanadium, 1.5 % iron), and

- 1.1.25 *Grade 39*—UNS R53390. Titanium alloy (0.25 % iron, 0.4 % silicon).

NOTE 1—H grade material is identical to the corresponding numeric grade (that is, Grade 2H = Grade 2) except for the higher guaranteed minimum UTS, and may always be certified as meeting the requirements of its corresponding numeric grade. Grades 2H, 7H, 16H, and 26H are intended primarily for pressure vessel use.

1.2 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.

1.3 *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:

- A370 Test Methods and Definitions for Mechanical Testing of Steel Products
- E8 Test Methods for Tension Testing of Metallic Materials
- E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
- E213 Practice for Ultrasonic Testing of Metal Pipe and Tubing
- E426 Practice for Electromagnetic (Eddy Current) Examination of Seamless and Welded Tubular Products, Titanium, Austenitic Stainless Steel and Similar Alloys
- E499 Test Methods for Leaks Using the Mass Spectrometer Leak Detector in the Detector Probe Mode
- E1409 Test Method for Determination of Oxygen and Nitrogen in Titanium and Titanium Alloys by Inert Gas Fusion
- E1447 Test Method for Determination of Hydrogen in Titanium and Titanium Alloys by Inert Gas Fusion Thermal Conductivity/Infrared Detection Method
- E1941 Test Method for Determination of Carbon in Refractory and Reactive Metals and Their Alloys by Combustion Analysis
- E2371 Test Method for Analysis of Titanium and Titanium Alloys by Direct Current Plasma and Inductively Coupled Plasma Atomic Emission Spectrometry (Performance-Based Test Methodology)
- E2626 Guide for Spectrometric Analysis of Reactive and Refractory Metals (Withdrawn 2017)

3. Terminology

3.1 Lot Definitions:

3.1.1 *castings, n*—a lot shall consist of all castings produced from the same pour.

3.1.2 *ingot, n*—no definition required.

3.1.3 *rounds, flats, tubes, and wrought powder metallurgical products (single definition, common to nuclear and non-nuclear standards), n*—a lot shall consist of a material of the same size, shape, condition, and finish produced from the same ingot or powder blend by the same reduction schedule and the same heat treatment parameters. Unless otherwise agreed between manufacturer and purchaser, a lot shall be limited to

the product of an 8 h period for final continuous anneal, or to a single furnace load for final batch anneal.

3.1.4 *sponge, n*—a lot shall consist of a single blend produced at one time.

3.1.5 *weld fittings, n*—definition is to be mutually agreed upon between manufacturer and the purchaser.

4. Ordering Information

4.1 Orders for material to this specification shall include the following information, as required:

- 4.1.1 Quantity,
- 4.1.2 Grade number (Section 1),
- 4.1.3 Diameter and wall thickness (Note 2) (Section 12),
- 4.1.4 Length (Section 12),
- 4.1.5 Method of manufacture and finish (Sections 5 and 13),
- 4.1.6 Restrictive chemistry, if desired (Section 6 and Table 1),
- 4.1.7 Product analysis, if desired (Section 7 and Table 2),
- 4.1.8 Special mechanical properties, if desired (Section 8 and Table 3),
- 4.1.9 Nondestructive tests (Section 11),
- 4.1.10 Packaging (Section 23),
- 4.1.11 Inspection (Section 17), and
- 4.1.12 Certification (Section 21).

NOTE 2—Tube is available to specified outside diameter and wall thickness. Average OD and wall are the standard. Maximum or minimum OD or wall should be stated.

4.2 Optional supplementary requirements are provided and, when one or more of these are desired, each shall be so stated in the order.

5. Materials and Manufacture

5.1 Seamless tube shall be made from hollow billet by any cold reducing or cold drawing process that will yield a product meeting the requirements of this specification. Seamless tube is produced with a continuous periphery in all stages of manufacturing operations.

5.2 Welded tube shall be made from annealed, flat-rolled product by an automatic arc-welding process or other method of welding that will yield a product meeting the tensile requirements found in Table 3 of this specification. Welded tubing shall be heat treated by at least a stress relief after forming and welding. Use of filler material is not permitted.

5.3 Welded/cold worked tube (WCS) shall be made from welded tube manufactured as specified in 5.2. The welded tube shall be sufficiently cold worked to final size in order to transform the cast weld microstructure into a typical equiaxed microstructure in the weld upon subsequent heat treatment. The product shall meet the requirements for seamless tube of this specification.

5.4 Grades 9, 18 and 28, which, at the option of the purchaser, can be furnished in either the annealed or the cold worked and stress relieved condition, defined as at a minimum temperature of 600°F (316°C) for not less than 30 min.

TABLE 1 Chemical Requirements

Composition, Weight Percent^{A,B,C,D,E}

Grade	UNS Number	Carbon, max.	Oxygen range or max.	Nitrogen, max.	Hydrogen, max.	Iron range or max.	Aluminum	Vanadium	Palladium	Ruthenium	Nickel	Molybdenum	Chromium	Cobalt	Zirconium	Niobium	Tin	Silicon	Other Elements, max. each	Other Elements, max. total
1	R50250	0.08	0.18	0.03	0.015	0.20	--	--	--	--	--	--	--	--	--	--	--	--	0.1	0.4
2/2H	R50400	0.08	0.25	0.03	0.015	0.30	--	--	--	--	--	--	--	--	--	--	--	--	0.1	0.4
3	R50550	0.08	0.35	0.05	0.015	0.30	--	--	--	--	--	--	--	--	--	--	--	--	0.1	0.4
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
7/7H	R52400	0.08	0.25	0.03	0.015	0.30	--	--	0.12-0.25	--	--	--	--	--	--	--	--	--	0.1	0.4
9	R56320	0.08	0.15	0.03	0.015	0.25	2.5-3.5	2.0-3.0	--	--	--	--	--	--	--	--	--	--	0.1	0.4
11	R52250	0.08	0.18	0.03	0.015	0.20	--	--	0.12-0.25	--	--	--	--	--	--	--	--	--	0.1	0.4
12	R53400	0.08	0.25	0.03	0.015	0.30	--	--	--	--	0.6-0.9	0.2-0.4	--	--	--	--	--	--	0.1	0.4
13	R53413	0.08	0.10	0.03	0.015	0.20	--	--	--	0.04-0.06	0.4-0.6	--	--	--	--	--	--	--	0.1	0.4
14	R53414	0.08	0.15	0.03	0.015	0.30	--	--	--	0.04-0.06	0.4-0.6	--	--	--	--	--	--	--	0.1	0.4
15	R53415	0.08	0.25	0.05	0.015	0.30	--	--	--	0.04-0.06	0.4-0.6	--	--	--	--	--	--	--	0.1	0.4
16/16H	R52402	0.08	0.25	0.03	0.015	0.30	--	--	0.04-0.08	--	--	--	--	--	--	--	--	--	0.1	0.4
17	R52252	0.08	0.18	0.03	0.015	0.20	--	--	0.04-0.08	--	--	--	--	--	--	--	--	--	0.1	0.4
18	R56322	0.08	0.15	0.03	0.015	0.25	2.5-3.5	2.0-3.0	0.04-0.08	--	--	--	--	--	--	--	--	--	0.1	0.4
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
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26/26H	R52404	0.08	0.25	0.03	0.015	0.30	--	--	--	0.08-0.14	--	--	--	--	--	--	--	--	0.1	0.4
27	R52254	0.08	0.18	0.03	0.015	0.20	--	--	--	0.08-0.14	--	--	--	--	--	--	--	--	0.1	0.4
28	R56323	0.08	0.15	0.03	0.015	0.25	2.5-3.5	2.0-3.0	--	0.08-0.14	--	--	--	--	--	--	--	--	0.1	0.4
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
31	R53532	0.08	0.35	0.05	0.015	0.30	--	--	0.04-0.08	--	--	--	--	0.20-0.80	--	--	--	--	0.1	0.4
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
33	R53442	0.08	0.25	0.03	0.015	0.30	--	--	0.01-0.02	0.02-0.04	0.35-0.55	--	0.1-0.2	--	--	--	--	--	0.1	0.4
34	R53445	0.08	0.35	0.05	0.015	0.30	--	--	0.01-0.02	0.02-0.04	0.35-0.55	--	0.1-0.2	--	--	--	--	--	0.1	0.4
35	R56340	0.08	0.25	0.05	0.015	0.20-0.80	4.0-5.0	1.1-2.1	--	--	--	1.5-2.5	--	--	--	--	--	0.20-0.40	0.1	0.4
36	R58450	0.04	0.16	0.03	0.015	0.03	--	--	--	--	--	--	--	--	--	42.0-47.0	--	--	0.1	0.4
37	R52815	0.08	0.25	0.03	0.015	0.30	1.0-2.0	--	--	--	--	--	--	--	--	--	--	--	0.1	0.4

TABLE 1 *Continued*Composition, Weight Percent^{A,B,C,D,E}

Grade	UNS Number	Carbon, max.	Oxygen range or max.	Nitrogen, max.	Hydrogen, max.	Iron range or max.	Aluminum	Vanadium	Palladium	Ruthenium	Nickel	Molybdenum	Chromium	Cobalt	Zirconium	Niobium	Tin	Silicon	Other Elements, max. each	Other Elements, max. total
38	R54250	0.08	0.20-0.30	0.03	0.015	1.2-1.8	3.5-4.5	2.0-3.0	--	--	--	--	--	--	--	--	--	--	0.1	0.4
39	R53390	0.08	0.15	0.03	0.015	0.15-0.40	—	—	—	—	—	—	—	—	—	—	—	0.30-0.50	0.1	0.4

^A At minimum, the analysis of samples from the top and bottom of the ingot shall be completed and reported for all elements listed for the respective grade in this table.

^B Final product hydrogen shall be reported. Ingot hydrogen need not be reported. Lower hydrogen may be obtained by negotiation with the manufacturer.

^C Single values are maximum. The percentage of titanium is determined by difference.

^D Other elements need not be reported unless the concentration level is greater than 0.1 % each, or 0.4 % total. Other elements may not be added intentionally. Other elements may be present in titanium or titanium alloys in small quantities and are inherent to the manufacturing process. In titanium these elements typically include aluminum, vanadium, tin, chromium, molybdenum, niobium, zirconium, hafnium, bismuth, ruthenium, palladium, yttrium, copper, silicon, cobalt, tantalum, nickel, boron, manganese, and tungsten.

^E The purchaser may, in the written purchase order, request analysis for specific elements not listed in this specification.

TABLE 2 Permissible Variations in Product Analysis

Element	%	
	Maximum or Specified Range	Permissible Variation in Product Analysis
Aluminum	0.5 to 2.5	±0.20
Aluminum	2.5 to 3.5	±0.40
Carbon	0.10	+0.02
Chromium	0.1 to 0.2	±0.02
Cobalt	0.2 to 0.8	±0.05
Hydrogen	0.015	+0.002
Iron	0.80	+0.15
Iron	1.2 to 1.8	±0.20
Molybdenum	0.2 to 0.4	±0.03
Molybdenum	1.5 to 4.5	±0.20
Nickel	0.3 to 0.9	±0.05
Niobium	>30	±0.50
Nitrogen	0.05	+0.02
Oxygen	0.30	+0.03
Oxygen	0.31 to 0.40	±0.04
Palladium	0.01 to 0.02	±0.002
Palladium	0.04 to 0.25	±0.02
Ruthenium	0.02 to 0.04	±0.005
Ruthenium	0.04 to 0.06	±0.005
Ruthenium	0.08 to 0.14	±0.01
Silicon	0.06 to 0.50	±0.02
Vanadium	2.0 to 3.0	±0.15
Residuals ^A (each)	0.1	+0.02

^A A residual is an element present in a metal or an alloy in small quantities inherent to the manufacturing process but not added intentionally. In titanium these elements include aluminum, vanadium, tin, iron, chromium, molybdenum, niobium, zirconium, hafnium, bismuth, ruthenium, palladium, yttrium, copper, silicon, cobalt, tantalum, nickel, boron, manganese, and tungsten.

6. Chemical Requirements

6.1 The titanium shall conform to the chemical requirements prescribed in Table 1.

6.1.1 The elements listed in Table 1 are intentional alloy additions or elements that are inherent to the manufacture of titanium sponge, ingot, or mill product.

6.1.2 Elements intentionally added to the melt must be identified, analyzed, and reported in the chemical analysis.

6.2 When agreed upon by the producer and the purchaser and requested by the purchaser in the written purchase order, chemical analysis shall be completed for specific residual elements not listed in this specification.

7. Product Analysis

7.1 When requested by the purchaser and stated in the purchase order, product analysis for any elements listed in Table 1 shall be made on the completed product.

7.1.1 Elements other than those listed in Table 1 are deemed to be capable of occurring in the grades listed in Table 1 by, and only by way of, unregulated or unanalyzed scrap additions to the ingot melt. Therefore, product analysis for elements not listed in Table 1 shall not be required unless specified and shall be considered to be in excess of the intent of this specification.

7.2 Product analysis tolerances, listed in Table 2, do not broaden the specified heat analysis requirements, but cover variations between different laboratories in the measurement of chemical content. The manufacturer shall not ship the finished product that is outside the limits specified in Table 1 for the applicable grade.

8. Tensile Requirements

8.1 The room temperature tensile properties of the tube in the condition normally supplied shall conform to the requirements prescribed in Table 3. Mechanical properties for conditions other than those given in this table may be established by agreement between the manufacturer and the purchaser. (See Test Methods E8.)

9. Flattening Test

9.1 Tubing shall withstand, without cracking, flattening under a load applied gradually at room temperature until the distance between the load platens is not more than H in. H is calculated as follows:

$$H, \text{ in. (mm)} = \frac{(1+e)t}{e+t/D} \quad (1)$$

where:

H = the minimum flattened height, in. (mm),
 t = the nominal wall thickness, in. (mm), and
 D = the nominal tube diameter, in. (mm).

For Grades 1, 2, 2H, 7, 7H, 11, 13, 14, 16, 16H, 17, 26, 26H, 27, 30, 33, and 39:

$$e = 0.07 \text{ in. for all diameters} \quad (2)$$

For Grade 3, 31, and 34:

$$e = 0.04 \text{ through 1 in. diameter} \quad (3)$$

$$e = 0.06 \text{ over 1 in. diameter} \quad (4)$$

For Grades 9, 12, 15, 18, 28, 35, 36, 37, and 38:

e shall be negotiated between the producer and the purchaser.

9.1.1 For welded tubing, the weld shall be positioned on the 90 or 270° centerline during loading so as to be subjected to a maximum stress.

9.1.2 When low D-to-t ratio tubular products are tested, because the strain imposed due to geometry is unreasonably high on the inside surface at the six and twelve o'clock locations, cracks at these locations shall not be cause for rejection if the D-to-t ratio is less than ten (10).

9.2 The results from all calculations are to be rounded to two decimal places. Examination for cracking shall be by the unaided eye.

9.3 Welded tube shall be subjected to a reverse flattening test in accordance with Annex 2 of Test Methods and Definitions A370. A section of the tube, approximately 4 in. (102 mm) long, that is slit longitudinally 90° either side of the weld, shall be opened and flattened with the weld at the point of maximum bend. No cracking is permitted.

10. Flaring Test

10.1 For tube 3½ in. (88 mm) in outside diameter and smaller, and 0.134 in. (3.4 mm) in wall thickness and thinner, a section of tube approximately 4 in. (102 mm) in length shall withstand being flared with a tool having a 60° included angle until the tube at the mouth of the flare has been expanded in accordance with Table 4. The flared end shall show no cracking or rupture visible to the unaided eye. Flaring tests on larger

TABLE 3 Tensile Requirements

Grade	Tensile Strength, min		Yield Strength, 0.2 % Offset				Elongation in 2 in. or 50 mm, min, %
	ksi	MPa	min		max		
			ksi	MPa	ksi	MPa	
1 ^A	35	240	20	138	45	310	24
2 ^A	50	345	40	275	65	450	20
2H ^{A,B,C}	58	400	40	275	65	450	20
3 ^A	65	450	55	380	80	550	18
7 ^A	50	345	40	275	65	450	20
7H ^{A,B,C}	58	400	40	275	65	450	20
9 ^D	125	860	105	725	...	...	10
9 ^A	90	620	70	483	...	...	15 ^E
11 ^A	35	240	20	138	45	310	24
12 ^A	70	483	50	345	...	...	18 ^E
13 ^A	40	275	25	170	...	...	24
14 ^A	60	410	40	275	...	...	20
15 ^A	70	483	55	380	...	...	18
16 ^A	50	345	40	275	65	450	20
16H ^{A,B,C}	58	400	40	275	65	450	20
17 ^A	35	240	20	138	45	310	24
18 ^D	125	860	105	725	...	...	10
18 ^A	90	620	70	483	...	...	15 ^E
26	50	345	40	275	65	450	20
26H ^{A,B,C}	58	400	40	275	65	450	20
27	35	240	20	138	45	310	24
28	90	620	70	483	...	...	15
30	50	345	40	275	65	450	20
31	65	450	55	380	80	550	18
33	50	345	40	275	65	450	20
34	65	450	55	380	80	550	18
35	130	895	120	828	...	...	5
36	65	450	60	410	95	655	10
37	50	345	31	215	65	450	20
38	130	895	115	794	...	...	10
39	75	515	60	410	90	620	20

^A Properties for material in the annealed condition.

^B Material is identical to the corresponding numeric grade (that is, Grade 2H = Grade 2) except for the higher guaranteed minimum UTS, and may always be certified as meeting the requirements of its corresponding numeric grade. Grade 2H, 7H, 16H, and 26H are intended primarily for pressure vessel use.

^C The H grades were added in response to a user association request based on its study of over 5200 commercial Grade 2, 7, 16, and 26 test reports, where over 99 % met the 58 ksi minimum UTS.

^D Properties for cold-worked and stress-relieved material.

^E Elongation for welded tubing manufactured from continuously cold rolled and annealed strip from coils for Grades 9, 12, and 18 will be 12 %.

TABLE 4 Flaring Requirements

Grade	Expansion of Inside Diameter, min, %
1	22
2, 2H	20
3	17
7, 7H	20
9 ^A	20
11	22
12	17
13	22
14	20
15	17
16, 16H	20
17	22
18 ^A	20
26, 26H	20
27	22
28 ^A	20
30	20
31	17
33	20
34	17
35	10
37	20
38	15
39	20

^A Annealed.

diameter tube or tubing outside the range of Table 4 shall be as agreed upon between the manufacturer and the purchaser.

11. Nondestructive Tests

11.1 *Welded Tubes* shall be nondestructively tested using the following procedures:

11.1.1 Eddy Current Test, see 11.3.

11.1.2 Ultrasonic Test, see 11.4.1.1.

11.1.3 Hydrostatic Test, see 11.6, or pneumatic test, see 11.7.

11.2 *Seamless and Welded/Cold Worked Tubes* shall be nondestructively tested using the following procedures:

11.2.1 Ultrasonic Test, see 11.4.1.2.

11.2.2 Eddy Current Test, see 11.3, or hydrostatic test, see 11.6, or pneumatic test, see 11.7.

11.3 *Eddy Current Test:*

11.3.1 Perform the nondestructive test in accordance with Practice E426. The entire volume of the tube shall be tested.

11.3.1.1 *Drilled Hole*—The calibration tube shall contain three or more holes, equally spaced circumferentially around the tube and longitudinally separated by a sufficient distance to allow distinct identification of the signal from each hole. The

holes shall be drilled radially and completely through the tube wall, with care being taken to avoid distortion of the tube while drilling. The holes shall not be larger than 0.031 in (0.787 mm) in diameter. As an alternative, the producer may choose to drill one hole and run the calibration standard through the test coil three times, rotating the tube approximately 120° each time. More passes with smaller angular increments may be used, provided testing of the full 360° of the coil is obtained. For welded tubing, one of the multiple holes or the single hole may be drilled in the weld. As an option, the single hole may be drilled in the skelp.

11.4 Ultrasonic Testing:

11.4.1 Perform the nondestructive test in accordance with Practice E213.

11.4.1.1 *Welded Tubing*—A longitudinal notch 0.031 in. (0.787 mm) or less in width and 0.5 in. (12.7 mm) or less in length shall be machined on a radial parallel to the tube axis on the outside and inside of the tube. The notch depth shall not exceed 10 % of the nominal wall of the tube or 0.004 in. (0.102 mm), whichever is greater. The length of the notch shall be compatible with the testing method, and the notches shall be located 180 degrees from the weld. The entire volume of the tube shall be tested.

11.4.1.2 *Seamless and Welded/Cold Worked Tubing*—Longitudinal and transverse notches not exceeding 0.010 in. (0.25 mm) in width and 10 % of the nominal tube wall or 0.004 in. (0.102 mm), whichever is greater, in depth shall be machined on the inner and outer surfaces of the tube. The length of the notches shall not exceed 0.125 in. (3.18 mm).

11.5 Any tubes showing an indication in excess of that obtained from the calibration standard shall be set aside and be subject to rework, retest, or rejection. A tube thus set aside may be examined further for confirmation of the presence of a defect and may be resubmitted for inspection if no defect is found. Any tube may also be resubmitted for inspection if reworked so as to remove the defect within the specified diameter, and wall thickness tolerances are established from Table 5 (rework by weld repair is not permitted).

11.6 Hydrostatic Test:

11.6.1 Each tube so tested shall withstand, without showing bulges, leaks, or other defects, an internal hydrostatic pressure that will produce in the tube wall a stress of 50 % of the minimum specified yield strength at room temperature. This pressure shall be determined by the equation:

$$P = \frac{SEt}{R_o - 0.4t} \quad (5)$$

where:

- P = minimum hydrostatic test pressure, psi (or MPa),
 S = allowable fiber stress of one half the minimum yield strength, psi (or MPa),
 t = wall thickness, in. (or mm),
 R_o = outside tube radius, in. (or mm),
 E = 0.85 welded tube, and
 E = 1.0 seamless and welded/cold worked tube.

11.6.2 The maximum hydrostatic test pressure shall not exceed 2500 psi (17.2 MPa) for sizes 3 in. (76 mm) and under, or 2800 psi (19.3 MPa) for sizes over 3 in. Hydrostatic pressure shall be maintained for not less than 5 s. When requested by the purchaser and so stated in the order, tube in sizes 14 in. (356 mm) in diameter and smaller shall be tested to one and one half times the specified working pressure, provided the fiber stress corresponding to those test pressures does not exceed one half the minimum specified yield strength of the material as determined by the equation given in 11.3. When one and one half times the working pressure exceeds 2800 psi (19.3 MPa), the hydrostatic test pressure shall be a matter of agreement between the manufacturer and purchaser.

11.7 *Pneumatic Test*—Each tube so tested shall withstand an internal air pressure of 100 psi (0.69 MPa), minimum, for 5 s, minimum, without showing evidence of leakage. The test method used shall permit easy detection of any leakage by using the pressure differential method or by placing the tube under water. Any evidence of leakage shall be cause for rejection of that tube.

12. Permissible Variation in Dimensions

12.1 Variations in dimensions from those specified shall not exceed the amounts prescribed in Table 5.

12.2 *Length*—When tube is ordered cut to length, the length shall not be less than that specified, but a variation of 1/8 in. (3.2 mm) will be permitted on tube up to 24 ft (7.3 m) inclusive. For lengths over 24 ft (7.3 m), an additional over tolerance of 1/8 in. (3.2 mm) for each 10 ft (3.05 m) or fraction thereof shall be permissible up to 1/2 in. (13 mm) maximum.

12.3 *Straightness*—The tube shall be free of bends or kinks, and the maximum uniform bow shall not exceed the values given in Table 6.

TABLE 5 Permissible Variations in Outside Dimensions Based on Individual Measurements

Outside Diameter, in. (mm)	Diameter Tolerance, in. (mm) ^{A,B,C}	Permissible Variations ^D in Wall Thickness, t , %
Under 1 (25.4), excl	±0.004 (±0.102)	±10
1 to 1½ (25.4 to 38.1), excl	±0.005 (±0.127)	±10
1½ to 2 (38.1 to 50.8), excl	±0.006 (±0.152)	±10
2 to 2½ (50.8 to 63.5), excl	±0.007 (±0.178)	±10
2½ to 3½ (63.5 to 88.9), excl	±0.010 (±0.254)	±10

^A These permissible variations in outside diameter apply only to tubes as finished at the mill before subsequent swaging, expanding, bending, polishing, or other fabricating operations.

^B When minimum diameter tubes are ordered, tolerances are all on the plus side and shall be double the values shown.

^C When maximum diameter tubes are ordered, tolerances are all on the minus side and shall be double the values shown.

^D When minimum wall tubes are ordered, tolerances are all plus and shall be double the values shown.

TABLE 6 Straightness

Length, ft (m)	Maximum Curvature Depth of Arc
Over 3 to 6 (0.91 to 1.83), incl	1/8 in. (3.2 mm)
Over 6 to 8 (1.83 to 2.44), incl	3/16 in. (4.8 mm)
Over 8 to 10 (2.44 to 3.05), incl	1/4 in. (6.4 mm)
Over 10 (3.05)	1/4 in./any 10 ft (2.1 mm/m)

12.4 *Squareness of Cut*—The angle of cut of the end of any tube may depart from square by not more than 0.016 in./in. of diameter.

12.5 *Outside Diameter:*

12.5.1 *Welded Tubes*—The outside diameter of welded tubes shall not vary from that specified by more than the amounts given in Table 5 as measured by “go” and “no go” ring gages. The dimensions of the ring gage shall be as described in 12.5.1.1. For tube diameters not listed in Table 5, the dimensional tolerances shall be as agreed upon by the purchaser and the manufacturer or supplier.

12.5.1.1 The inside diameter dimension of the “go” ring gage shall be equal to the nominal tube diameter plus the plus tolerance plus 0.002 in. The length of the “go” ring gage shall be the larger of 1 in. (25.4 mm) or the tube diameter.

12.5.1.2 The inside diameter dimension of the “no go” ring gage shall be equal to the nominal tube diameter minus the minus tolerance. The length of the “no go” ring gage shall be the larger of 1 in. or the nominal tube diameter.

12.5.2 *Seamless and Welded/Cold Worked Tubes*—The outside diameter of seamless and welded/cold worked tubes shall not vary from that specified by more than the amounts given in Table 5 as measured by any method agreed upon between the purchaser and the manufacturer or supplier. For tube diameters not listed in Table 5, the dimensional tolerances shall be as agreed upon by the purchaser and the manufacturer or supplier.

13. Finish

13.1 The finished tube shall be clean and free of foreign material, shall have smooth ends free of burrs, and shall be free of injurious external and internal imperfections. Minor defects may be removed, provided the dimensional tolerances of Section 12 are not exceeded.

14. Number of Tests

14.1 One sample shall be selected from lots of 5000 ft (1600 m) or less. For lots greater than 5000 ft (1600 m), one sample shall be selected from the first 5000 ft (1600 m), and one additional sample shall be selected from each additional 5000 ft (1600 m) or less in the lot. Samples are to be selected at random, and in no case shall more than one sample be taken from a single tube length. The size of the lot may be either the manufactured lot or the purchased lot at the manufacturer’s option.

14.1.1 Chemical composition of the lot shall be the ingot manufacturer’s analysis, except for hydrogen, which shall be determined on each sample from the lot. For welded tube only, hydrogen determination shall be one (1) tube analysis per strip coil.

14.1.2 One tension test shall be made on each sample.

14.1.3 One flattening test in accordance with 9.1 shall be made on each sample.

14.1.4 One reverse flattening test in accordance with 9.3 shall be made on each sample.

14.1.5 One flaring test in accordance with 10.1 shall be made on each sample.

14.2 If any test specimen shows defective machining or develops flaws due to preparation, the specimen may be discarded and another substituted.

14.3 If the percent of elongation of any tension test specimen is less than that specified in 8.1, and any part of the fracture is more than $\frac{3}{4}$ in. (19 mm) from the center of the gage length as indicated by scratches marked on the specimen before testing, the specimen may be discarded and another substituted.

14.4 Each length of finished tube shall be examined by the nondestructive test specified in 11.1.

15. Retests

15.1 If the results of any chemical or mechanical property test lot are not in conformance with the requirements of this specification, the lot may be retested at the option of the manufacturer. The frequency of the retest will double the initial number of tests. If the results of the retest conform to the specification, the retest values will become the test values for certification. Only original conforming test results or the conforming retest results shall be reported to the purchaser. If the results for the retest fail to conform to the specification, the material will be rejected in accordance with Section 20.

16. Test Specimens and Methods of Testing

16.1 The test specimens and the tests required by this specification shall conform to those described in Test Methods and Definitions A370.

16.2 All routine mechanical tests shall be made at room temperature.

16.3 The chemical analysis shall normally be conducted using the ASTM standard test methods referenced in 2.1. Other industry standard methods may be used where the ASTM test methods referenced in 2.1 do not adequately cover the elements in the material or by agreement between the producer and purchaser. Alternate techniques are discussed in Guide E2626.

17. Inspection

17.1 All tests and inspection required by this specification shall be made at the place of manufacture prior to shipment and at the manufacturer’s expense unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works. When specified in the order, the manufacturer shall notify the purchaser in time so that the purchaser may have his inspector present to witness any part of the tests that may be desired.

17.2 When agreed upon in writing between the manufacturer and the purchaser, a certification that the material conforms to the requirements of this specification shall be the basis for acceptance of the material. Otherwise, the manufacturer shall report to the purchaser or his representative the results of the chemical analyses and mechanical tests made in accordance with this specification.

18. Rounding-Off Procedure

18.1 For purposes of determining conformance with the specifications contained herein, an observed or calculated

value shall be rounded off to the nearest “unit” in the last right-hand significant digit used in expressing the limiting value. This is in accordance with the round-off method of Practice E29.

19. Referee Test and Analysis

19.1 In the event of disagreement between the manufacturer and the purchaser on the conformance of the material to the requirements of this specification, a mutually acceptable referee shall perform the tests in question using the ASTM standard methods in 2.1. The referee’s testing shall be used in determining conformance of the material to this specification.

20. Rejection

20.1 Material not conforming to this specification or to authorized modifications shall be subject to rejection. Unless otherwise specified, rejected material may be returned to the manufacturer at the manufacturer’s expense, unless the purchaser receives within 3 weeks of notice of rejection other instructions for disposition.

21. Certification

21.1 The manufacturer shall supply at least one copy of the report certifying that the material supplied has been manufactured, inspected, sampled, and tested in accordance with the requirements of this specification and that the results

of chemical analysis, tensile, and other tests meet the requirements of this specification for the grade specified. The report shall include results of all chemical analysis, tensile tests, and all other tests required by the specification.

22. Product Marking

22.1 Each length of tube ½ in. (13 mm) in outside diameter and larger, manufactured in accordance with this specification, shall be legibly marked, either by stenciling, stamping, or rolling, with the manufacturer’s private identifying mark, the ASTM designation, the tube class, the grade, and heat number. On smaller than ½ in. outside diameter tubing that is bundled, the same information may be legibly stamped on a metal tag securely attached to each bundle.

NOTE 3—Average outside diameter and wall thickness are the standard for this specification. If maximum or minimum OD or wall are ordered, the tubes should be marked accordingly.

23. Packaging and Package Marking

23.1 The tube shall be packaged in accordance with the manufacturer’s standard practice, unless otherwise agreed upon between the manufacturer and the purchaser and so stated in the purchase order.

24. Keywords

24.1 seamless tubing; titanium; titanium alloy; tubing; welded/cold worked tubing; welded tubing

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirements become part of the specification when specified in the purchase order or contract.

S1. Traverse Ultrasonic Test (Welded Tubing)

S1.1 A transverse notch 0.031 in. (0.787 mm) or less in width and 0.5 in. (12.7 mm) or less in length shall be machined on a radial perpendicular to the tube axis on the outside and inside of the tube in addition to the longitudinal notch. The notch depth shall not exceed 10 % of the nominal wall of the tube or 0.004 in. (0.102 mm), whichever is greater. Perform the nondestructive test in accordance with Practice E213.

S2. Helium Leak Test (Welded Tubing)

S2.1 The tubing shall be tested by the helium leak test according to Practice E499 in substitution of the pneumatic test required in 11.7. The maximum allowable leak rate shall be 9.87×10^{-4} std cm³/s (1 x 10⁻³ mbar l/s) quantified with a calibrated leak.