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Standard Specification for Seamless and Welded Titanium and Titanium Alloy Tubes for Condensers and Heat Exchangers[1]

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

1. Scope

1.1 This specification[2] covers the requirements for ~~23~~24 grades of titanium and titanium alloy tubing intended for surface condensers, evaporators, and heat exchangers, as follows:

1.1.1 *Grade 1*—Unalloyed titanium,
1.1.2 *Grade 2*—Unalloyed titanium,
1.1.3 *Grade 3*—Unalloyed titanium,
1.1.4 *Grade 7*—Unalloyed titanium plus 0.12 to 0.25 % palladium,
1.1.5 *Grade 9*—Titanium alloy (3 % aluminum, 2.5 % vanadium),
1.1.6 *Grade 11*—Unalloyed titanium plus 0.12 to 0.25 % palladium,
1.1.7 *Grade 12*—Titanium alloy (0.3 % molybdenum, 0.8 % nickel),
1.1.8 *Grade 13*—Titanium alloy (0.5 % nickel, 0.05 % ruthenium),
1.1.9 *Grade 14*—Titanium alloy (0.5 % nickel, 0.05 % ruthenium),
1.1.10 *Grade 15*—Titanium alloy (0.5 % nickel, 0.05 % ruthenium),
1.1.11 *Grade 16*—Unalloyed titanium plus 0.04 to 0.08 % palladium,
1.1.12 *Grade 17*—Unalloyed titanium plus 0.04 to 0.08 % palladium,
1.1.13 *Grade 18*—Titanium alloy (3 % aluminum, 2.5 % vanadium) plus 0.04 to 0.08 % palladium,
1.1.14 *Grade 26*—Unalloyed titanium plus 0.08 to 0.14 % ruthenium,
1.1.15 *Grade 27*—Unalloyed titanium plus 0.08 to 0.14 % ruthenium,
1.1.16 *Grade 28*—Titanium alloy (3 % aluminum, 2.5 % vanadium) plus 0.08 to 0.14 % ruthenium,
1.1.17 *Grade 30*—Titanium alloy (0.3 % cobalt, 0.05 % palladium),
1.1.18 *Grade 31*—Titanium alloy (0.3 % cobalt, 0.05 % palladium),
1.1.19 *Grade 33*—Titanium alloy (0.4 % nickel, 0.015 % palladium, 0.025 % ruthenium, 0.15 % chromium),
1.1.20 *Grade 34*—Titanium alloy (0.4 % nickel, 0.015 % palladium, 0.025 % ruthenium, 0.15 % chromium),
1.1.21 *Grade 35*—Titanium alloy (4.5 % aluminum, 2 % molybdenum, 1.6 % vanadium, 0.5 % iron, 0.3 % silicon),
1.1.22 *Grade 36*—Titanium alloy (45 % niobium), ~~and~~
1.1.23 *Grade 37*~~—Titanium alloy (1.5% aluminum).~~
~~1.2Tubing covered by this specification shall be heat treated by at least a stress relief as defined in~~ —Titanium alloy (1.5 % aluminum), and
1.1.24 *Grade 38*—Titanium alloy (4 % aluminum, 2.5 % vanadium, 1.5 % iron).

1.2 Tubing covered by this specification shall be heat treated by at least a stress relief as defined in 5.3.

1.3 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.

2. Referenced Documents

2.1 *ASTM Standards:* [3]

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products
E 8 Test Methods for Tension Testing of Metallic Materials

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[1] This specification is under the jurisdiction of ASTM Committee B10 on Reactive and Refractory Metals and Alloys and is the direct responsibility of Subcommittee B10.01 on Titanium.

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[2] For ASME Boiler and Pressure Vessel Code applications, see related Specification SB-338 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.

E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
E 120 Test Methods for Chemical Analysis of Titanium and Titanium Alloys
E 1409 Test Method for Determination of Oxygen and Nitrogen in Titanium and Titanium Alloys by the Inert Gas Fusion Technique
E 1447 Test Method for Determination of Hydrogen in Titanium and Titanium Alloys by the Inert Gas Fusion Thermal Conductivity/Infrared Detection Method

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.

TABLE 1 Chemical Requirements[A]

Element	Composition, %							
	Grade 1	Grade 2	Grade 3	Grade 7	Grade 9	Grade 11	Grade 12	Grade 13
Nitrogen, max	0.03	0.03	0.05	0.03	0.03	0.03	0.03	0.03
Carbon, max	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Hydrogen,[B,C] max	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
Iron, max	0.20	0.30	0.30	0.30	0.25	0.20	0.30	0.20
Oxygen, max	0.18	0.25	0.35	0.25	0.15	0.18	0.25	0.10
Aluminum	...	...	...	...	2.5–3.5	...	...	...
Vanadium	...	...	...	...	2.0–3.0	...	...	...
Tin	...	...	...	...	...	...	...	...
Ruthenium	...	...	...	...	...	...	...	0.04–0.06
Palladium	...	...	...	0.12–0.25	...	0.12–0.25	...	...
Cobalt	...	...	...	...	...	...	...	...
Molybdenum	...	...	...	...	...	...	0.2–0.4	...
Chromium	...	...	...	...	...	...	...	...
Nickel	...	...	...	...	...	...	0.6–0.9	0.4–0.6
Niobium	...	...	...	...	...	...	...	...
Zirconium	...	...	...	...	...	...	...	...
Silicon	...	...	...	...	...	...	...	...
Residuals,[D,E,F] max each	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Residuals,[D,E,F] max total	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Titanium[G]	balance	balance	balance	balance	balance	balance	balance	balance

Element	Composition, %								
~~Grade 13~~		Grade 14	Grade 15	Grade 16	Grade 17	Grade 18	Grade 26	Grade 27	Grade 28
Nitrogen, max	0.03~~0.03~~		0.05	0.03	0.03	0.03	0.03	0.03	0.03
Carbon, max	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	
Hydrogen,[B,C] max	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	
Iron, max~~0.20~~		0.30	0.30	0.30	0.20	0.25	0.30	0.20	0.25
Oxygen, max~~0.10~~		0.15	0.25	0.25	0.18	0.15	0.25	0.18	0.15
Aluminum	...	...	...	...~~—~~		2.5–3.5	...	...	2.5–3.5
Vanadium	...	...	...	...~~—~~		2.0–3.0	...	...	2.0–3.0
Tin	...	...	...	...	...	...	...	...	
Ruthenium	0.04–0.06	0.04–0.06~~0.04–0.06~~		...	...	...	0.08–0.14	0.08–0.14	0.08–0.14
Palladium	...	...~~—~~		0.04–0.08	0.04–0.08	0.04–0.08	...	...	...
Cobalt	...	...	...	...	...	...	...	...	
Molybdenum	...	...	...	...	...	...	...	...	
Chromium	...	...	...	...	...	...	...	...	
Nickel	0.4–0.6	0.4–0.6~~0.4–0.6~~		...	...	...	...	...	...
Niobium	...	...	...	...	...	...	...	...	
Zirconium	...	...	...	...	...	...	...	...	
Silicon	...	...	...	...	...	...	...	...	
Residuals,[D,E,F] max each	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	

Element	Composition, %								
~~Grade 13~~		Grade 14	Grade 15	Grade 16	Grade 17	Grade 18	Grade 26	Grade 27	Grade 28
Residuals,[D,E,F] max total	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	
Titanium[G]	balance	balance	balance	balance	balance	balance	balance	balance	

TABLE 1 *Continued*

Element										
~~Grade 27~~	~~Grade 28~~		Grade 30	Grade 31	Grade 33	Grade 34	Grade 35	Grade 36	Grade 37	Grade 38
Nitrogen, max	0.03~~0.03~~	~~0.03~~		0.05	0.03	0.05	0.05	0.03	0.03	0.03
Carbon, max	0.08	0.08	0.08	0.08	0.08~~0.08~~	~~0.08~~	0.04	0.08	0.08	
Hydrogen,[B,C] max	0.015	0.015	0.015	0.015	0.015~~0.015~~	~~0.015~~	0.0035	0.015	0.015	
Iron, max or range~~0.20~~	~~0.25~~		0.30	0.30	0.30	0.30	0.20-0.80	0.03	0.30	1.2–1.8
~~Oxygen, max~~	~~0.18~~	~~0.15~~	Oxygen, max or range	0.25	0.35	0.25	0.35	0.25	0.16	0.25
Aluminum	...~~2.5–3.5~~		...	...	...~~...~~		4.0-5.0	...	1.0-2.0	3.5–4.5
Vanadium	...~~2.0–3.0~~		...	...	...~~...~~		1.1-2.1	...	...	2.0–3.0
~~Tin~~	~~...~~	~~...~~	~~...~~	~~...~~	~~...~~	~~.....~~	~~...~~	~~...~~		
Tin	...	...	...	...	...	...	...	...		
Ruthenium~~0.08–0.14~~	~~0.08–0.14~~		...	...	0.02-0.04	0.02-0.04	...	...	...	...
Palladium~~...~~	~~...~~		0.04–0.08	0.04–0.08	0.01-0.02	0.01-0.02	...	...	...	...
Cobalt~~...~~	~~...~~		0.20–0.80	0.20–0.80	...	...	...	...	...	...
Molybdenum	...	...	...	...~~...~~	~~...~~		1.5-2.5	...	...	...
Chromium	...	...~~...~~	~~...~~		0.1-0.2	0.1-0.2	...	...	...	...
Nickel	...	...~~...~~	~~...~~		0.35-0.55	0.35-0.55	...	...	...	...
Niobium	...	...	...	...	...~~...~~	~~...~~	42.0–47.0	...	...	
~~Zirconium~~	~~...~~	~~...~~	~~...~~	~~...~~	~~...~~	~~.....~~	~~...~~	~~...~~		
Zirconium	...	...	...	...	...	...	...	...		
Silicon	...	...	...	...~~...~~	~~...~~		0.20-0.40	...	...	...
~~Residuals,[D,E,F] max each~~	~~0.1~~	~~0.1~~	~~0.1~~	~~0.1~~	~~0.1~~	~~0.10.1~~	~~0.1~~	~~0.1~~		
Residuals,[D,E,F] max each	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1		
~~Residuals,[D,E,F] max total~~	~~0.4~~	~~0.4~~	~~0.4~~	~~0.4~~	~~0.4~~	~~0.40.4~~	~~0.4~~	~~0.4~~		
Residuals,[D,E,F] max total	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4		
Titanium[G]	balance	balance~~balance~~	~~balance~~		Remainder	Remainder	Remainder	Remainder	Remainder	balance

[A] Analysis shall be completed for all elements listed in this table for each grade. The analysis results for the elements not quantified in the table need not be reported unless the concentration level is greater than 0.1 % each or 0.4 % total.

[B] Lower hydrogen may be obtained by negotiation with the manufacturer.

[C] Final product analysis.

[D] Need not be reported.

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

[F] The purchaser may, in his written purchase order, request analysis for specific residual elements not listed in this specification.

[G] The percentage of titanium is determined by difference.

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 (Section 12) (Note 1),

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 1—Tube is available to specified outside diameter and wall thickness (state minimum or average wall).

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 flat-rolled product by an automatic arc-welding process or other method of welding that will yield a product meeting the requirements of this specification. Use of a filler material is not permitted.

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
~~30Cobalt~~	~~0.2 to 0.8~~	~~±0.05~~
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 0.40	±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.

TABLE 3 Tensile Requirements

Grade	Tensile Strength, min		Yield Strength, 0.2% Offset				Elongation in 2 in. or 50 mm, min, %
			min		max		
	ksi	MPa	ksi	MPa	ksi	MPa	
1[A]	35	240	20	138	45	310	24
2[A]	50	345	40	275	65	450	20
3[A]	65	450	55	380	80	550	18
7[A]	50	345	40	275	65	450	20
9[B]	125	860	105	725	...	...	10
9[A]	90	620	70	483	...	...	15[C]
11[A]	35	240	20	138	45	310	24
12[A]	70	483	50	345	...	...	18[C]
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
17[A]	35	240	20	138	45	310	24
18[B]	125	860	105	725	...	...	10
18[A]	90	620	70	483	...	...	15[C]
26	50	345	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

[A] Properties for material in the annealed condition.
[B] Properties for cold-worked and stress-relieved material.
[C] Elongation for welded tubing manufactured from continuously cold rolled and annealed strip from coils for Grades 9, 12, and 18 will be 12 %.

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 The tube shall be furnished in the annealed condition with the exception of 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.

6. *Chemical Requirements* 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 E 8.)

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, 7, 11, 13, 14, 16, 17, 26, 27, 30, and 33:

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

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 ~~37:~~ 38:

e ~~shallbenegotiatedbetweentheproducerandthepurchaser~~ 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 Supplement II of Test Methods and Definitions A 370. 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