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

This standard is issued under the fixed designation B 338; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

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

1. Scope

1.1 This specification[2] covers the requirements for 23 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).

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

1.3

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
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[4]
E 1409 Test Method for Determination of Oxygen in Titanium and Titanium Alloys by the Inert Gas Fusion Technique

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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.

[4] Withdrawn.

E 1447 Test Method for Determination of Hydrogen in Titanium and Titanium Alloys by the Inert Gas Fusion Thermal Conductivity Method

3. Terminology

3.1 *Lot Definitions:*

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

3.1.2 *ingot*—no definition required.

3.1.3 *rounds, flats, tubes, and wrought powder metallurgical products (single definition, common to nuclear and non-nuclear standards.)* —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*—a lot shall consist of a single blend produced at one time.

3.1.5 *weld fittings*—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
Nitrogen, max	0.03	0.03	0.05	0.03	0.03	0.03	0.03
Carbon, max	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
Iron, max	0.20	0.30	0.30	0.30	0.25	0.20	0.30
Oxygen, max	0.18	0.25	0.35	0.25	0.15	0.18	0.25
Aluminum	...	...	...	...	2.5–3.5	...	...
Vanadium	...	...	...	...	2.0–3.0	...	...
Tin	...	...	...	...	...	...	...
Ruthenium	...	...	...	...	...	...	...
Palladium	...	...	...	0.12–0.25	...	0.12–0.25	...
Cobalt	...	...	...	...	...	...	...
Molybdenum	...	...	...	...	...	...	0.2–0.4
Chromium	...	...	...	...	...	...	...
Nickel	...	...	...	...	...	...	0.6–0.9
Niobium	...	...	...	...	...	...	...
Zirconium	...	...	...	...	...	...	...
Silicon	...	...	...	...	...	...	...
Residuals,[D,E,F] max each	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
Titanium[G]	balance	balance	balance	balance	balance	balance	balance

Element	Composition, %						
	Grade 13	Grade 14	Grade 15	Grade 16	Grade 17	Grade 18	Grade 26
Nitrogen, max	0.03	0.03	0.05	0.03	0.03	0.03	0.03
Carbon, max	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
Iron, max	0.20	0.30	0.30	0.30	0.20	0.25	0.30
Oxygen, max	0.10	0.15	0.25	0.25	0.18	0.15	0.25
Aluminum	...	...	...	...	...	2.5–3.5	...
Vanadium	...	...	...	...	...	2.0–3.0	...
Tin	...	...	...	...	...	...	...
Ruthenium	0.04–0.06	0.04–0.06	0.04–0.06	...	...	...	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
Residuals,[D,E,F] max total	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Titanium[G]	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
Nitrogen, max	0.03	0.03	0.03	0.05	0.03	0.05	0.05	0.03	0.03
Carbon, max	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.04	0.08
Hydrogen,[B,C] max	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.0035	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
Oxygen, max	0.18	0.15	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
Vanadium	...	2.0–3.0	...	...	...	...	1.1-2.1	...	...
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	...	...	...	...	...	...	...	...	...
Silicon	...	...	...	...	...	...	0.20-0.40	...	...
Residuals,[D,E,F] max each	0.1	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	0.4
Titanium[G]	balance	balance	balance	balance	Remainder	Remainder	Remainder	Remainder	Remainder

[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.

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.

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
Hydrogen	0.015	+0.002
Iron	0.80	+0.15
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

[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 %.

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.