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Standard Specification for Seamless and Welded Titanium and Titanium Alloy Tubes for Condensers and Heat Exchangers¹

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

1. Scope*

1.1 This specification² 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*—Unalloyed titanium,
- 1.1.2 *Grade 2*—Unalloyed titanium,
 - 1.1.2.1 *Grade 2H*—Unalloyed titanium (Grade 2 with 58 ksi minimum UTS),
- 1.1.3 *Grade 3*—Unalloyed titanium,
- 1.1.4 *Grade 7*—Unalloyed titanium plus 0.12 to 0.25 % palladium,
 - 1.1.4.1 *Grade 7H*—Unalloyed titanium plus 0.12 to 0.25 % palladium (Grade 7 with 58 ksi minimum UTS),
- 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,
 - 1.1.11.1 *Grade 16H*—Unalloyed titanium plus 0.04 to 0.08 % palladium (Grade 16 with 58 ksi minimum UTS),
- 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,
 - 1.1.14.1 *Grade 26H*—Unalloyed titanium plus 0.08 to 0.14 % ruthenium (Grade 26 with 58 ksi minimum UTS),
- 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),
- 1.1.23 *Grade 37*—Titanium alloy (1.5 % aluminum), and
- 1.1.24 *Grade 38*—Titanium alloy (4 % aluminum, 2.5 % vanadium, 1.5 % iron).

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.

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.

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 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.

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

2. Referenced Documents

2.1 ASTM Standards:³

- 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
- E1409 Test Method for Determination of Oxygen and Nitrogen in Titanium and Titanium Alloys by the Inert Gas Fusion Technique
- 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 Atomic Emission Plasma Spectrometry
- E2626 Guide for Spectrometric Analysis of Reactive and Refractory Metals

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 (Section 12) (Note 2),
 - 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 (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 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.

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.

TABLE 1 Chemical Requirements

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

Grade	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	0.08	0.18	0.03	0.015	0.20	—	—	—	—	—	—	—	—	—	—	—	—	0.1	0.4
2	0.08	0.25	0.03	0.015	0.30	—	—	—	—	—	—	—	—	—	—	—	—	0.1	0.4
2H	0.08	0.25	0.03	0.015	0.30	—	—	—	—	—	—	—	—	—	—	—	—	0.1	0.4
3	0.08	0.35	0.05	0.015	0.30	—	—	—	—	—	—	—	—	—	—	—	—	0.1	0.4
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
7	0.08	0.25	0.03	0.015	0.30	—	—	0.12-0.25	—	—	—	—	—	—	—	—	—	0.1	0.4
7H	0.08	0.25	0.03	0.015	0.30	—	—	0.12-0.25	—	—	—	—	—	—	—	—	—	0.1	0.4
9	0.08	0.15	0.03	0.015	0.25	2.5-3.5	2.0-3.0	—	—	—	—	—	—	—	—	—	—	0.1	0.4
11	0.08	0.18	0.03	0.015	0.20	—	—	0.12-0.25	—	—	—	—	—	—	—	—	—	0.1	0.4
12	0.08	0.25	0.03	0.015	0.30	—	—	—	—	0.6-0.9	0.2-0.4	—	—	—	—	—	—	0.1	0.4
13	0.08	0.10	0.03	0.015	0.20	—	—	—	0.04-0.06	0.4-0.6	—	—	—	—	—	—	—	0.1	0.4
14	0.08	0.15	0.03	0.015	0.30	—	—	—	0.04-0.06	0.4-0.6	—	—	—	—	—	—	—	0.1	0.4
15	0.08	0.25	0.05	0.015	0.30	—	—	—	0.04-0.06	0.4-0.6	—	—	—	—	—	—	—	0.1	0.4
16	0.08	0.25	0.03	0.015	0.30	—	—	0.04-0.08	—	—	—	—	—	—	—	—	—	0.1	0.4
16H	0.08	0.25	0.03	0.015	0.30	—	—	0.04-0.08	—	—	—	—	—	—	—	—	—	0.1	0.4
17	0.08	0.18	0.03	0.015	0.20	—	—	0.04-0.08	—	—	—	—	—	—	—	—	—	0.1	0.4
18	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
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
26	0.08	0.25	0.03	0.015	0.30	—	—	—	0.08-0.14	—	—	—	—	—	—	—	—	0.1	0.4
26H	0.08	0.25	0.03	0.015	0.30	—	—	—	0.08-0.14	—	—	—	—	—	—	—	—	0.1	0.4
27	0.08	0.18	0.03	0.015	0.20	—	—	—	0.08-0.14	—	—	—	—	—	—	—	—	0.1	0.4
28	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	0.08	0.35	0.05	0.015	0.30	—	—	0.04-0.08	—	—	—	—	0.20-0.80	—	—	—	—	0.1	0.4
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
33	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	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	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	0.04	0.16	0.03	0.0035	0.03	—	—	—	—	—	—	—	—	42.0-47.0	—	—	—	0.1	0.4
36	0.04	0.16	0.03	0.015	0.03	—	—	—	—	—	—	—	—	42.0-47.0	—	—	—	0.1	0.4
37	0.08	0.25	0.03	0.015	0.30	1.0-2.0	—	—	—	—	—	—	—	—	—	—	—	0.1	0.4
38	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

^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 0.40	±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.

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:

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