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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 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.

~~1.2The~~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]

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 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 Inert Gas Fusion Thermal Conductivity/Infrared Detection Method
E 1941 Test Method for Determination of Carbon in Refractory and Reactive Metals and Their Alloys
E 2371 Test Method for Analysis of Titanium and Titanium Alloys by Atomic Emission Plasma Spectrometry
E 2626 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.

~~5.4Grades~~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.

El-ement	Composition, % Weight Percent[A,B,C,D,E]																	
	Carbon, max	Oxygen range 2 or max.	Nitrogen, max	Hydrogen, max	Iron range 7 or max.	Aluminum	Vanadium	Palladium	Ruthenium	Nickel	Molybdenum	Chromium	Cobalt	Zirconium	Niobium	Tin	Silicon	Other Elements, max, total
	Elements, max, each																	
Nitrogen, max	0.03	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	0.08									
Carbon, max										0.03								
0.08Hydrogen,[B,C] max		0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015							0.015
1	0.08	0.18	0.03	0.015	0.20	- -	- -	- -	- -	- -								0.015
Iron, max	0.20	0.30	0.30	0.30	0.30	0.30	0.1	0.4										
Iron, max- - 2	- -	- -	- -	- -	- -	- -	0.1	0.4										
2	0.08	0.25	0.20	0.015	0.30	0.20												
2	0.08	0.25	0.03	0.015	0.30	0.20												
Oxygen, max	0.18	0.25	0.25	0.35	0.25	0.25	0.15	0.18	0.25	0.10								
Oxygen, max- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	0.10								
Aluminum	...	...	...4															
Aluminum- -	- -	0.1	0.4															
2H	...	...	...	2.5–3.5	...	...	...											
2H	0.08	0.25	0.03	0.015	0.30	- -	...											
Vanadium	...	...	...	...	...	...	2.0–3.0	...	...	...								
Vanadium- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	...								
Tin	...	...4																
Tin- - 3	0.1	0.4																
3	0.08	0.35	0.05	0.015	0.30	- -	- -	...										
Ruthenium	...	...	...	...	...	...	...	...	...	0.1	04–0.06							
Ruthenium- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	0.1	0.4							
Palladium	...	...	...	...	0.12–0.25	0.12–0.25	...	0.12–0.25	...	...								
—	—	—	—	—	—	—	—	—	—	...								
Cobalt	...	...	...	...	...	...	...	...	...	...								
Cobalt—	—	—	—	—	—	—	—	—	...	...—								
Molybdenum	...	...	...	...	...	...	...	...	0.2–0.4	...								

Composition, % Weight Percent[A,B,C,D,E]

El- Grade- ment	GCarbon, made 1x.	GOxygen radnge 2 or max.	GNitradoge 2Hn, max.	GraHydroge 3n, max.	GIron radnge 7 or max.	Grade 7HAluminum	GrVanade 9ium	GrPallade 11ium	GradRuthe 12nium	GNickel	Molybdenum	Chromium	Cobadlt	Zirconium	Niobium	Tin	Silicon	Othe 13	
—	—	—	—	—	—	—	—	—	— ...	...									
Chromium	...	...	...	...	...	...	...	...		...									
Chromium—	—	—	—	—	—	—	—	—	...	...—									
Nickel	...	...	...	...	...	...	...	...	0.6–0.9	0.4–0.6									
										0.4–0.6									
—	—	—	—	—	—	—	—	—	— ...										
Niobium	...	...	...	...	...	...	...	...		...									
Niobium—	—	—	—	—	—	—	—	—	...	...—									
Zirconium	...	...	...	...	...	...	...	...	...	...									
7	0.08	0.25	0.03	0.015	0.30	- -	- -	0.12-0.25	- -	...									
Silicon	...	...	...	...	...	...	...	...	...	...									
Silicon- -	- -	- -	- -	- -	- -	- -	- -	0.1	0...	...4									
Residuals[D,E,F], max each	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	—	—	—	—	—	—	—	—	0.1Residuals[D,E,F], max total	0.4
7H	0.08	0.25	0.03	0.015	0.30	- -	- -	0.12-0.25	- -	- -	- -	- -	- -	- -	- -	- -	- -	0.1	0.4
	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4										
9	0.08	0.15	0.03	0.015	0.25	2.5-3.5	2.0-3.0	- -	0.4	balance									
Titanium[G]	balance	balance	balance	balance	balance	balance	balance	balance	balance										
Titanium[G]- -	- -	- -	- -	- -	- -	- -	- -	- -	0.1	balance									

Composition, %0.4 Element 11	Grade 140.08	Grade0.158	Grade 160.03	Grade0.016H5	Grade 170.20	Grade 18- -	Grade 26- -	Grade0.126H- 0.25	Grade 27- -	- -	- -
										Carbon, max0.6-0.9	
Nitrogen, max12	0.038	0.025	0.03	0.0315	0.030	0.03- -	0.03- -	0.03- -	0.03- -		0.2-08.4
		Hydrogen,[B,C] max									
13	0.08	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
13	0.08	0.10	0.03	0.015	0.20	- -	- -	- -	0.04-0.06	0.4-0.6	- -
Iron, max	0.30	0.30	0.30	0.015	0.30	0.20	0.25	0.30	0.30	0.20	Oxygen, max
14	0.08	0.15	0.03	0.015	0.30	- -	- -	- -	0.04-0.06	0.4-0.6	- -
15	0.08	0.25	0.18	Aluminum	...	...	...	...	...	2.5–3.5	...
15	0.08	0.25	0.05	0.015	0.30	- -	- -	- -	0.04-0.06	0.4-0.6	- -
16	2.0–3.0	...	...	...	Tin	...	...	...	...	...	...
16	0.08	0.25	0.03	0.015	0.30	- -	- -	0.04-0.08	- -	- -	- -
16H	...	...	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
16H	0.08	0.25	0.03	0.015	0.30	- -	- -	0.04-0.08	- -	- -	- -
17	...	...	...	...	...	...	Molybdenum	...	...	...	...
17	0.08	0.18	0.03	0.015	0.20	- -	- -	0.04-0.08	- -	- -	- -
18	...	...	...	...	...	...	...	Nickel	0.4–0.6	0.4–0.6	...

Composition, %0.4 Element											
11	Grade 140.08	Grade0.158	Grade 160.03	Grade0.016H5	Grade 170.20	Grade 18 -	Grade 26 -	Grade0.126H 0.25	Grade 27 -	- -	- -
Nitrogen, max12	0.038	0.025	0.03	0.0315	0.030	0.03 -	0.03 -	0.03 -	0.03 -	Carbon, max0.6-0.9	0.2-08.4
18	0.08	0.15	0.03	0.015	0.25	2.5-3.5	2.0-3.0	0.04-0.08	- -	- -	- -
Niobium	...	...	...	...	...	...	...	...	...	Zirconium	...
—	—	—	—	—	—	—	—	—	—	—	—
Silicon	...	...	...	...	...	...	...	...	...	Residuals,[D,E,F] max each	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	balance	balance	balance	balance	balance		
—	—	—	—	—	—	—	—	—	—		

Composition, %										
—	Element									
—	Grade 28	Grade 30	Grade 31	Grade 33	Grade 34	Grade 35	Grade 36	Grade 37	Grade 38	—
Nitrogen, max —	0.03 —	0.03 —	0.05 —	0.03 —	0.05 —	0.05 —	0.03 —	0.03 —	0.03 —	Carbon, max —
26	0.08	Hydrogen,[B,C] max	0.015	0.015	0.015	0.015	0.015	0.015	0.0035	0.015
26	0.08	0.25	0.03	0.015	0.30	- -	- -	- -	0.08-0.14	- -
Iron, max or range	0.08	0.25	0.30	0.30	0.30	0.30	0.20-0.80	—	0.08-0.14	—
26H	0.08	0.25	0.03	0.015	0.30	- -	- -	- -	0.08-0.14	- -
27	0.08	0.18	0.03	0.30	1.2-1.8	—	—	—	0.08-0.14	—
27	0.08	0.18	0.03	0.015	0.20	- -	- -	- -	0.08-0.14	- -
Oxygen, max or range	0.08	0.15	0.25	0.35	0.25	0.35	0.25	0.16	0.25	0.20-0.30
28	0.08	0.15	0.03	0.015	0.25	2.5-3.5	2.0-3.0	- -	0.08-0.14	- -
—	3.5-4.5	Vanadium	2.0-3.0	...	...	...	...	1.1-2.1	...	...
—	—	—	—	—	—	—	—	—	—	—
—	...	...	Ruthenium	0.08-0.14	...	...	0.02-0.04	0.02-0.04	...	...
—	—	—	—	—	—	—	—	—	—	—
31	...	...	...	Cobalt	...	0.20-0.80	0.20-0.80	...	...	...
31	0.08	0.35	0.05	0.015	0.30	- -	- -	0.04-0.08	- -	- -
Molybdenum	...	...	...	...	...	1.5-2.5	...	...	...	—
—	—	—	—	—	—	—	—	—	—	—
Chromium	...	...	...	0.1-0.2	0.30	—	—	0.01-0.02	0.02-0.04	0.35-0.55
33	0.08	0.25	0.03	0.015	0.30	- -	- -	0.01-0.02	0.02-0.04	0.35-0.55
Nickel	...	...	...	0.35-0.55	0.30	—	—	0.01-0.02	0.02-0.04	0.35-0.55
34	0.08	0.35	0.05	0.015	0.30	- -	- -	0.01-0.02	0.02-0.04	0.35-0.55
35	...	...	42.0-47.0	...	...	Zirconium	...	...	...	...
35	0.08	0.25	0.05	0.015	0.20-0.80	4.0-5.0	1.1-2.1	- -	- -	- -
Silicon	...	...	...	...	...	0.20-0.40	...	...	...	Residuals,[D,E,F] max each
36	0.04	0.16	0.03	0.0035	0.03	- -	- -	- -	- -	- -
Residuals,[D,E,F] max total	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	—
37	0.08	0.25	0.03	0.015	0.30	1.0-2.0	- -	- -	- -	- -
Titanium[G]	balance	balance	balance	Remainder	Remainder	Remainder	Remainder	Remainder	balance	—

Composition, %

Element	Carbon, max	Nitrogen, max	Grade 28	Grade 30	Grade 31	Grade 33	Grade 34	Grade 35	Grade 36	Grade 37	Grade 38
Grade 38	0.08	0.03	0.20-0.30	0.03	0.015	1.2-1.8	3.5-4.5	2.0-3.0	- -	- -	0.03

[A] At minimum, the analysis of shall be completeds for all eom the top and bots listom of thed ingothi s thabll be f cormpleach gradte. Thed analysisd resulportsed for th all e elements not quant lified insthe table need n for t bhe resported unless theconcentration level is greatder in than 0.1% each or 0.4%is totable.

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

[C] FSingle val pues arode maximum. The percentange of titalysnium is determined by difference.

[D] NOther 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] 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 thise written purchase order, request analysis for specific r esidualelements not listed in this specification. G The percentage of titanium is determined by difference.