



Designation: ~~B861-09~~ Designation: B861 - 10

Standard Specification for Titanium and Titanium Alloy Seamless Pipe¹

This standard is issued under the fixed designation B861; 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 covers the requirements for 34 grades of titanium and titanium alloy seamless pipe intended for general corrosion resisting and elevated temperature service as follows:

- 1.1.1 *Grade 1*—Unalloyed titanium, low oxygen,
- 1.1.2 *Grade 2*—Unalloyed titanium, standard oxygen,
 - 1.1.2.1 *Grade 2H*—Unalloyed titanium (Grade 2 with 58 ksi minimum UTS),
- 1.1.3 *Grade 3*—Unalloyed titanium, medium oxygen,
- 1.1.4 *Grade 5*—Titanium alloy (6 % aluminum, 4 % vanadium),
- 1.1.5 *Grade 7*—Unalloyed titanium plus 0.12 to 0.25 % palladium, standard oxygen,
 - 1.1.5.1 *Grade 7H*—Unalloyed titanium plus 0.12 to 0.25 % palladium (Grade 7 with 58 ksi minimum UTS),
- 1.1.6 *Grade 9*—Titanium alloy (3 % aluminum, 2.5 % vanadium),
- 1.1.7 *Grade 11*—Unalloyed titanium plus 0.12 to 0.25 % palladium, low oxygen,
- 1.1.8 *Grade 12*—Titanium alloy (0.3 % molybdenum, 0.8 % nickel),
- 1.1.9 *Grade 13*—Titanium alloy (0.5 % nickel, 0.05 % ruthenium), low oxygen,
- 1.1.10 *Grade 14*—Titanium alloy (0.5 % nickel, 0.05 % ruthenium), standard oxygen,
- 1.1.11 *Grade 15*—Titanium alloy (0.5 % nickel, 0.05 % ruthenium), medium oxygen,
- 1.1.12 *Grade 16*—Unalloyed titanium plus 0.04 to 0.08 % palladium, standard oxygen,
 - 1.1.12.1 *Grade 16H*—Unalloyed titanium plus 0.04 to 0.08 % palladium (Grade 16 with 58 ksi minimum UTS),
- 1.1.13 *Grade 17*—Unalloyed titanium plus 0.04 to 0.08 % palladium, low oxygen,
- 1.1.14 *Grade 18*—Titanium alloy (3 % aluminum, 2.5 % vanadium plus 0.04 to 0.08 % palladium),
- 1.1.15 *Grade 19*—Titanium alloy (3 % aluminum, 8 % vanadium, 6 % chromium, 4 % zirconium, 4 % molybdenum),
- 1.1.16 *Grade 20*—Titanium alloy (3 % aluminum, 8 % vanadium, 6 % chromium, 4 % zirconium, 4 % molybdenum) plus 0.04 to 0.08 % palladium,
- 1.1.17 *Grade 21*—Titanium alloy (15 % molybdenum, 3 % aluminum, 2.7 % niobium, 0.25 % silicon),
- 1.1.18 *Grade 23*—Titanium alloy (6 % aluminum, 4 % vanadium, extra low interstitial, ELI),
- 1.1.19 *Grade 24*—Titanium alloy (6 % aluminum, 4 % vanadium) plus 0.04 to 0.08 % palladium,
- 1.1.20 *Grade 25*—Titanium alloy (6 % aluminum, 4 % vanadium) plus 0.3 to 0.8 % nickel and 0.04 to 0.08 % palladium,
- 1.1.21 *Grade 26*—Unalloyed titanium plus 0.08 to 0.14 % ruthenium,
 - 1.1.21.1 *Grade 26H*—Unalloyed titanium plus 0.08 to 0.14 % ruthenium (Grade 26 with 58 ksi minimum UTS),
- 1.1.22 *Grade 27*—Unalloyed titanium plus 0.08 to 0.14 % ruthenium,
- 1.1.23 *Grade 28*—Titanium alloy (3 % aluminum, 2.5 % vanadium plus 0.08 to 0.14 % ruthenium),
- 1.1.24 *Grade 29*—Titanium alloy (6 % aluminum, 4 % vanadium, extra low interstitial, ELI plus 0.08 to 0.14 % ruthenium),
- 1.1.25 *Grade 33*—Titanium alloy (0.4 % nickel, 0.015 % palladium, 0.025 % ruthenium, 0.15 % chromium),
- 1.1.26 *Grade 34*—Titanium alloy (0.4 % nickel, 0.015 % palladium, 0.025 % ruthenium, 0.15 % chromium),
- 1.1.27 *Grade 35*—Titanium alloy (4.5 % aluminum, 2 % molybdenum, 1.6 % vanadium, 0.5 % iron, 0.3 % silicon),
- 1.1.28 *Grade 36*—Titanium alloy (45 % niobium),
- 1.1.29 *Grade 37*—Titanium alloy (1.5 % aluminum), and
- 1.1.30 *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

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.

Current edition approved Aug-May 1, 2009-2010. Published August-2009-May 2010. Originally approved in 1995. Last previous edition approved in 2008-2009 as ~~B861-08a~~ B861 - 09. DOI: 10.1520/B0861-109.

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

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.

2. Referenced Documents

2.1 *ASTM Standards:*²

- A370 [Test Methods and Definitions for Mechanical Testing of Steel Products](#)
- E29 [Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications](#)
- E539 [Test Method for Analysis of Titanium Alloys by X-Ray Fluorescence Spectrometry](#)
- 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](#)

2.2 *ANSI/ASME Standards:*³

- B.1.20.1 Pipe Threads, General Purpose (Inch)
- B 36.10 Carbon, Alloy and Stainless Steel Pipes
- B 36.19M-1985 Stainless Steel Pipe

3. Terminology

3.1 *Definitions:*

3.1.1 *lot, n*—a number of pieces of pipe of the same nominal size and wall thickness manufactured by the same process from a single heat of titanium or titanium alloy and heat treated by the same furnace parameters in the same furnace.

3.1.2 *seamless pipe, n*—a hollow tubular product produced with a continuous periphery in all stages of manufacture.

4. Ordering Information

4.1 Orders for materials under this specification shall include the following information as required:

- 4.1.1 Quantity,
- 4.1.2 Grade number (Section 1 and Table 1),
- 4.1.3 Nominal pipe size and schedule (Table 2),
- 4.1.4 Diameter tolerance (Table 3),
- 4.1.5 Length tolerance (see 9.3),
- 4.1.6 Method of manufacture and finish (Sections 5 and 10),
- 4.1.7 Product analysis, if required (Sections 6 and 7; Table 1 and Table 4),
- 4.1.8 Mechanical properties, (Sections 8, 14, 15, and 16 and Table 5),
- 4.1.9 Packaging (Section 23),
- 4.1.10 Inspection and test reports (Sections 19, 20 and 21), and
- 4.1.11 Product marking (Section 22).

5. Manufacture

5.1 Seamless pipe may be manufactured by any method that will yield a product meeting the requirements of this specification.

5.2 Unless specified, cold worked pipe shall be heat treated at a temperature of not less than 1000°F (538°C). Hot worked pipe finishing above 1400°F (760°C) need not be further heat treated. The minimum heat treat conditions for Grade 9, 18, and 28 pipe delivered in the stress relieved condition shall be 600°F (316°C) for at least 30 min.

5.2.1 Grade 5, Grade 9, Grade 18, Grade 19, Grade 20, Grade 21, Grade 23, Grade 24, Grade 25, Grade 28, Grade 29, Grade 35, Grade 36, and Grade 38 alloys may be supplied in the following conditions:

- 5.2.1.1 *Grade 5, Grade 23, Grade 24, Grade 25, Grade 29, Grade 35, or Grade 36*—annealed or aged condition,
- 5.2.1.2 *Grade 9, Grade 18, Grade 28, or Grade 38*—cold-worked and stress-relieved or annealed,
- 5.2.1.3 *Grade 9, Grade 18, Grade 23, Grade 28, or Grade 29*—transformed-beta condition, and

² 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.

³ Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, <http://www.ansi.org>.

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	0.03	0.015	0.30	--	--	--	--	--	--	--	--	--	--	--	--	0.1	0.4
4	0.08	0.40	0.05	0.015	0.50	--	--	--	--	--	--	--	--	--	--	--	--	0.1	0.4
5	0.08	0.20	0.05	0.015	0.40	5.5-6.75	3.5-4.5	--	--	--	--	--	--	--	--	--	--	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	--	--	0.6-0.9	0.2-0.4	--	--	--	--	--	--	0.1	0.4
12	0.08	0.25	0.03	0.015	0.30	--	--	--	0.04-0.06	0.4-0.6	--	--	--	--	--	--	--	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	--	--	--	0.04-0.08	--	--	--	--	--	--	--	--	0.1	0.4
16	0.08	0.25	0.03	0.015	0.30	--	0.04-0.08	--	0.04-0.08	--	--	--	--	--	--	--	--	0.1	0.4
16H	0.08	0.25	0.03	0.015	0.30	--	0.04-0.08	--	0.04-0.08	--	--	--	--	--	--	--	--	0.1	0.4
17	0.08	0.18	0.03	0.015	0.20	--	0.04-0.08	--	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
19	0.05	0.12	0.03	0.02	0.30	3.0-4.0	7.5-8.5	--	--	--	3.5-4.5	5.5-6.5	--	3.5-4.5	--	--	0.15	0.4	
20	0.05	0.12	0.03	0.02	0.30	3.0-4.0	7.5-8.5	0.04-0.08	--	--	3.5-4.5	5.5-6.5	--	3.5-4.5	--	--	0.15	0.4	
21	0.05	0.17	0.03	0.015	0.40	2.5-3.5	--	--	--	--	14.0-16.0	--	--	2.2-3.2	--	0.15-0.25	0.1	0.4	
23	0.08	0.13	0.03	0.0125	0.25	5.5-6.5	3.5-4.5	--	--	--	--	--	--	--	--	--	--	0.1	0.4
24	0.08	0.20	0.05	0.015	0.40	5.5-6.75	3.5-4.5	0.04-0.08	--	--	--	--	--	--	--	--	--	0.1	0.4
25	0.08	0.20	0.05	0.015	0.40	5.5-6.75	3.5-4.5	0.04-0.08	--	0.3-0.8	--	--	--	--	--	--	--	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
29	0.08	0.13	0.03	0.015	0.25	5.5-6.5	3.5-4.5	--	0.08-0.14	--	--	--	--	--	--	--	--	0.1	0.4
31	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
32	0.08	0.11	0.03	0.015	0.25	4.5-5.5	0.6-1.4	--	--	--	0.6-1.2	--	--	0.6-1.4	--	0.06-0.14	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 Dimensions of Pipe

NOTE 1—Schedule sizes conform to ANSI/ASME B36.19M-1985 (for “S” sizes) or B36.10 (for non-S sizes).

NOTE 2—The decimal thickness listed for the respective pipe sizes represent their nominal wall dimensions.

NPS Desig.	Outside Dia.		Nominal Wall Thickness																	
	in	mm	Schedule 5S ^A	Schedule 5 ^A	Schedule 10S ^A	Schedule 10 ^A	Schedule 40S	Schedule 40	Schedule 80S	Schedule 80	Schedule 40S		Schedule 40		Schedule 80S		Schedule 80			
			in	mm	in	mm	in	mm	in	mm	in	mm	in	mm	in	mm	in	mm	in	mm
1/8	0.405	10.29	x	x	0.049	1.24	0.049	1.24	0.068	1.73	0.068	1.73	0.068	1.73	0.095	2.41	0.095	2.41	0.095	2.41
1/4	0.540	13.72	x	x	0.065	1.65	0.065	1.65	0.088	2.24	0.088	2.24	0.088	2.24	0.119	3.02	0.119	3.02	0.119	3.02
3/8	0.675	17.15	x	x	0.065	1.65	0.065	1.65	0.091	2.31	0.091	2.31	0.091	2.31	0.126	3.20	0.126	3.20	0.126	3.20
1/2	0.840	21.34	0.065	1.65	0.083	2.11	0.083	2.11	0.109	2.77	0.109	2.77	0.109	2.77	0.147	3.73	0.147	3.73	0.147	3.73
3/4	1.050	26.67	0.065	1.65	0.083	2.11	0.083	2.11	0.113	2.87	0.113	2.87	0.113	2.87	0.154	3.91	0.154	3.91	0.154	3.91
1	1.315	33.40	0.065	1.65	0.109	2.77	0.109	2.77	0.133	3.38	0.133	3.38	0.133	3.38	0.179	4.55	0.179	4.55	0.179	4.55
1-1/4	1.660	42.16	0.065	1.65	0.109	2.77	0.109	2.77	0.140	3.56	0.140	3.56	0.140	3.56	0.191	4.85	0.191	4.85	0.191	4.85
1-1/2	1.900	48.26	0.065	1.65	0.109	2.77	0.109	2.77	0.145	3.68	0.145	3.68	0.145	3.68	0.200	5.08	0.200	5.08	0.200	5.08
2	2.375	60.32	0.065	1.65	0.109	2.77	0.109	2.77	0.154	3.91	0.154	3.91	0.154	3.91	0.218	5.54	0.218	5.54	0.218	5.54
2-1/2	2.875	73.02	0.083	2.11	0.120	3.05	0.120	3.05	0.203	5.16	0.203	5.16	0.203	5.16	0.276	7.01	0.276	7.01	0.276	7.01
3	3.500	88.90	0.083	2.11	0.120	3.05	0.120	3.05	0.216	5.49	0.216	5.49	0.216	5.49	0.300	7.62	0.300	7.62	0.300	7.62
3-1/2	4.000	101.60	0.083	2.11	0.120	3.05	0.120	3.05	0.226	5.74	0.226	5.74	0.226	5.74	0.318	8.08	0.318	8.08	0.318	8.08
4	4.500	114.30	0.083	2.11	0.120	3.05	0.120	3.05	0.237	6.02	0.237	6.02	0.237	6.02	0.337	8.56	0.337	8.56	0.337	8.56
5	5.563	141.30	0.109	2.77	0.134	3.40	0.134	3.40	0.258	6.55	0.258	6.55	0.258	6.55	0.375	9.53	0.375	9.53	0.375	9.53
6	6.625	168.27	0.109	2.77	0.134	3.40	0.134	3.40	0.280	7.11	0.280	7.11	0.280	7.11	0.432	10.97	0.432	10.97	0.432	10.97
8	8.625	219.07	0.109	2.77	0.148	3.76	0.148	3.76	0.322	8.18	0.322	8.18	0.322	8.18	0.500	12.70	0.500	12.70	0.500	12.70
10	10.75	273.05	0.134	3.40	0.165	4.19	0.165	4.19	0.365	9.27	0.365	9.27	0.365	9.27	0.500	12.70	0.500	12.70	0.500	12.70
12	12.75	323.85	0.156	3.96	0.180	4.57	0.180	4.57	0.375	9.53	0.375	9.53	0.375	9.53	0.500	12.70	0.500	12.70	0.500	12.70
14	14.00	355.60	0.156	3.96	0.188	4.78	0.188	4.78	x	x	x	x	x	x	x	x	x	x	x	x
16	16.00	406.40	0.165	4.19	0.188	4.78	0.188	4.78	x	x	x	x	x	x	x	x	x	x	x	x
18	18.00	457.20	0.165	4.19	0.188	4.78	0.188	4.78	x	x	x	x	x	x	x	x	x	x	x	x
20	20.00	508.00	0.188	4.78	0.218	5.54	0.218	5.54	x	x	x	x	x	x	x	x	x	x	x	x
22	22.00	558.80	0.188	4.78	0.218	5.54	0.218	5.54	x	x	x	x	x	x	x	x	x	x	x	x
24	24.00	609.60	0.218	5.54	0.250	6.35	0.250	6.35	x	x	x	x	x	x	x	x	x	x	x	x
26	26.00	660.40	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
28	28.00	711.20	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
30	30.00	762.00	0.250	6.35	0.312	7.92	0.312	7.92	x	x	x	x	x	x	x	x	x	x	x	x
32	32.00	812.80	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
34	34.00	863.60	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
36	36.00	914.40	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

^A Threading not permitted in accordance with ANSI B.1.20.1.

TABLE 3 Permissible Variations in Diameter

Nominal Outside Diameter (NPS) ^A	Permissible Variations in Outside Diameter	
	Over	Under
1/8 in. to 1 1/2 in. (3.2 mm to 38 mm)	1/64 in. (0.397 mm)	1/32 in. (0.794 mm)
over 1 1/2 in. to 4 in. (38 mm to 102 mm)	1/32 in. (0.794 mm)	1/32 in. (0.794 mm)
over 4 in. to 8 in. (102 mm to 203 mm)	1/16 in. (1.588 mm)	1/32 in. (0.794 mm)
over 8 in. to 18 in. (203 mm to 432 mm)	3/32 in. (2.382 mm)	1/32 in. (0.794 mm)

^A NPS = nominal pipe size.

TABLE 4 Permissible Variations in Product Analysis

Element	Product Analysis Limits, Permissible Variation	
	max or Range, %	in Product Analysis
Aluminum	0.5 to 2.5	±0.20
Aluminum	2.5 to 6.75	±0.40
Carbon	0.10	+0.02
Chromium	0.1 to 0.2	±0.02
Chromium	5.5 to 6.5	±0.30
Hydrogen	0.02	+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
Molybdenum	14.0 to 16.0	±0.50
Nickel	0.3 to 0.9	±0.05
Niobium	2.2 to 3.2	±0.15
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 0.08	±0.005
Palladium	0.12 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 4.5	±0.15
Vanadium	7.5 to 8.5	±0.40
Zirconium	3.5 to 4.5	±0.20
Residuals ^A (each)	0.15	+0.02

^A A residual is an element in a metal or alloy in small quantities inherent to the manufacturing process but not added intentionally.

5.2.1.4 *Grade 19, Grade 20, or Grade 21*—solution-treated or solution-treated and aged.

6. Chemical Requirements

6.1 The grades of titanium and titanium alloy metal covered by this specification shall conform to the requirements of the chemical compositions prescribed in Table 1.

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

6.1.1.1 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.

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

6.3 At least two samples for chemical analysis shall be tested to determine chemical composition. Samples shall be taken from the ingot or the opposite extremes of the product to be analyzed.

7. Product Analysis

7.1 When requested by the purchaser and stated in the purchase order, an analysis of chemical composition shall be made on the finished product.

7.2 The product analysis tolerances, listed in Table 4 do not broaden the specified analysis requirements, but cover variations between different laboratories in the measurement of chemical content. The manufacturer shall not ship finished product outside

TABLE 5 Tensile Requirements^A

Grade	Tensile Strength, min		Yield Strength (0.2 % Offset)				Elongation 2 in. or 50 mm
			min.		max.		gage length, min %
	ksi	(MPa)	ksi	(MPa)	ksi	(MPa)	
1	35	(240)	20	(138)	45	(310)	24
2	50	(345)	40	(275)	65	(450)	20
2H ^{B,C}	58	(400)	40	(275)	65	(450)	20
3	65†	(450)†	55	(380)	80	(550)	18
5	130	(895)	120	(828)	...	...	10
5 ^D	160	(1103)	150	(1034)	...	...	6
7	50	(345)	40	(275)	65	(450)	20
7H ^{B,C}	58	(400)	40	(275)	65	(450)	20
9	90	(620)	70	(483)	...	...	15
9 ^E	90	(620)	70	(483)	...	...	12
9 ^F	125	(860)	105	(725)	...	...	10
11	35	(240)	20	(138)	45	(310)	24
12	70	(483)	50	(345)	...	...	18
13	40	(275)	25	(170)	...	...	24
14	60	(410)	40	(275)	...	...	20
15	70	(483)	55	(380)	...	...	18
16	50	(345)	40	(275)	65	(450)	20
16H ^{B,C}	58	(400)	40	(275)	65	(450)	20
17	35	(240)	20	(138)	45	(310)	24
18	90	(620)	70	(483)	...	...	15
18 ^E	90	(620)	70	(483)	...	...	12
18 ^F	125	(860)	105	(725)	...	...	10
19 ^G	115	(793)	110	(759)	...	...	15
19 ^D	135	(930)	130	(897)	159	(1096)	10
19 ^H	165	(1138)	160	(1103)	185	(1276)	5
20 ^G	115	(793)	110	(759)	...	...	15
20 ^D	135	(930)	130	(897)	159	(1096)	10
20 ^H	165	(1138)	160	(1103)	185	(1276)	5
21 ^G	115	(793)	110	(759)	...	...	15
21 ^D	140	(966)	130	(897)	159	(1096)	15
21 ^H	170	(1172)	160	(1103)	185	(1276)	8
23	120	(828)	110	(759)	...	...	10
23 ^E	120	(828)	110	(759)	...	...	7.5 ^I , 6.0 ^J
24	130	(895)	120	(828)	...	...	10
25	130	(895)	120	(828)	...	...	10
26	50	(345)	40	(275)	65	(450)	20
26H ^{B,C}	58	(400)	40	(275)	65	(450)	20
27	35	(240)	20	(138)	45	(310)	24
28	90	(620)	70	(483)	...	...	15
28 ^E	90	(620)	70	(483)	...	...	12
28 ^F	125	(860)	105	(725)	...	...	10
29	120	(828)	110	(759)	...	...	10
29 ^E	120	(828)	110	(759)	...	...	7.5 ^I , 6.0 ^J
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 annealed condition except as noted.

^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 solution-treated and aged condition-Moderate strength (determined by aging temperature).

^E Properties for material in transformed-beta condition.

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

^G Properties for solution-treated condition.

^H Properties for solution-treated and aged condition-High strength (determined by aging temperature).

^I For product section or wall thickness values < 1.0 in.

^J For product section or wall thickness values ≥ 1.0 in.

† Tensile strength for Grade 3 was corrected editorially.