ASTM B861 / ASME SB861

Standard Specification for
Titanium and Titanium Alloy Seamless Pipe

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:

Grade 1—Unalloyed titanium, low oxygen,
Grade 2—Unalloyed titanium, standard oxygen,
Grade 2H—Unalloyed titanium (Grade 2 with 58 ksi minimum UTS),
Grade 3—Unalloyed titanium, medium oxygen,
Grade 5—Titanium alloy (6 % aluminum, 4 % vanadium),
Grade 7—Unalloyed titanium plus 0.12 to 0.25 % palladium, standard oxygen,
Grade 7H—Unalloyed titanium plus 0.12 to 0.25 % palladium (Grade 7 with 58 ksi minimum UTS),
Grade 9—Titanium alloy (3 % aluminum, 2.5 % vanadium),
Grade 11—Unalloyed titanium plus 0.12 to 0.25 % palladium, low oxygen,
Grade 12—Titanium alloy (0.3 % molybdenum, 0.8 % nickel),
Grade 13—Titanium alloy (0.5 % nickel, 0.05 % ruthenium), low oxygen,
Grade 14—Titanium alloy (0.5 % nickel, 0.05 % ruthenium), standard oxygen,
Grade 15—Titanium alloy (0.5 % nickel, 0.05 % ruthenium), medium oxygen,
Grade 16—Unalloyed titanium plus 0.04 to 0.08 % palladium, standard oxygen,
Grade 16H—Unalloyed titanium plus 0.04 to 0.08 % palladium (Grade 16 with 58 ksi minimum UTS),
Grade 17—Unalloyed titanium plus 0.04 to 0.08 % palladium, low oxygen,
Grade 18—Titanium alloy (3 % aluminum, 2.5 % vanadium plus 0.04 to 0.08 % palladium),
Grade 19—Titanium alloy (3 % aluminum, 8 % vanadium, 6 % chromium, 4 % zirconium, 4 % molybdenum),
Grade 20—Titanium alloy (3 % aluminum, 8 % vanadium, 6 % chromium, 4 % zirconium, 4 % molybdenum) plus 0.04 to 0.08 % palladium,
Grade 21—Titanium alloy (15 % molybdenum, 3 % aluminum, 2.7 % niobium, 0.25 % silicon),
Grade 23—Titanium alloy (6 % aluminum, 4 % vanadium, extra low interstitial, ELI),
Grade 24—Titanium alloy (6 % aluminum, 4 % vanadium) plus 0.04 to 0.08 % palladium,
Grade 25—Titanium alloy (6 % aluminum, 4 % vanadium) plus 0.3 to 0.8 % nickel and 0.04 to 0.08 % palladium,
Grade 26—Unalloyed titanium plus 0.08 to 0.14 % ruthenium,
Grade 26H—Unalloyed titanium plus 0.08 to 0.14 % ruthenium (Grade 26 with 58 ksi minimum UTS),
Grade 27—Unalloyed titanium plus 0.08 to 0.14 % ruthenium,
Grade 28—Titanium alloy (3 % aluminum, 2.5 % vanadium plus 0.08 to 0.14 % ruthenium),
Grade 29—Titanium alloy (6 % aluminum, 4 % vanadium, extra low interstitial, ELI plus 0.08 to 0.14 % ruthenium),
Grade 33—Titanium alloy (0.4 % nickel, 0.015 % palladium, 0.025 % ruthenium, 0.15 % chromium),
Grade 34—Titanium alloy (0.4 % nickel, 0.015 % palladium, 0.025 % ruthenium, 0.15 % chromium),

Grade 35—Titanium alloy (4.5 % aluminum, 2 % molybdenum, 1 .6 % vanadium, 0.5 % iron, 0.3 % silicon),
Grade 36—Titanium alloy (45 % niobium),
Grade 37—Titanium alloy (1 .5 % aluminum), and
Grade 38—Titanium alloy (4 % aluminum, 2.5 % vanadium, 1 .5 % iron).

A. Heat Treatment :-

1. Unless specified, cold worked pipe shall be heat treated at a temperature of not less than 1000°F (538°C).
2. Hot worked pipe finishing above 1400°F (760°C) need not be further heat treated.
3. 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.
4. Grade 5, Grade 23, Grade 24, Grade 25, Grade 29, Grade 35, or Grade 36—annealed or aged condition,
5. Grade 9, Grade 18, Grade 28, or Grade 38—cold worked and stress-relieved or annealed,
6. Grade 9, Grade 18, Grade 23, Grade 28, or Grade 29—transformed-beta condition, and
7. Grade 19, Grade 20, or Grade 21—solution-treated or solution-treated and aged.

B. Chemical Requirements :-

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.

Table 1

	Composition, Weight Percent [A,B,C,D,E]									
Grade	**C, max.**	**O_2 max.**	**N, max.**	**H, max.**	**Fe, max**	**Al**	**V**	**Other Component**	**Other Elements, max. each**	**Other Elements, max. total**
1	0.08	0.18	0.03	0.015	0.2	...	...	...	0.1	0.4
2	0.08	0.25	0.03	0.015	0.3	...	...	...	0.1	0.4
2H	0.08	0.25	0.03	0.015	0.3	...	...	...	0.1	0.4
3	0.08	0.35	0.05	0.015	0.3	...	...	...	0.1	0.4
4	0.08	0.4	0.05	0.015	0.5	...	...	...	0.1	0.4
5	0.08	0.2	0.05	0.015	0.4	5.5-6.75	3.5-4.5	...	0.1	0.4
—	—	—	—	—	—	—	—	—	—	—
7	0.08	0.25	0.03	0.015	0.3	...	...	Pd (0.12-0.25)	0.1	0.4
7H	0.08	0.25	0.03	0.015	0.3	...	...	Pd (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	0.2	...	...	Pd (0.12-0.25)	0.1	0.4
12	0.08	0.25	0.03	0.015	0.3	...	...	Ni (0.6-0.9), Mo (0.2-0.4)	0.1	0.4
13	0.08	0.1	0.03	0.015	0.2	...	...	Ru (0.04-0.06), Ni (0.04-0.06)	0.1	0.4
14	0.08	0.15	0.03	0.015	0.3	...	...	Ru (0.04-0.06), Ni (0.04-0.06)	0.1	0.4

15	0.08	0.25	0.05	0.015	0.3	...	...	Ru (0.04-0.06), Ni (0.04-0.06)	0.1	0.4
16	0.08	0.25	0.03	0.015	0.3	...	...	Pd (0.04-0.08)	0.1	0.4
16H	0.08	0.25	0.03	0.015	0.3	...	...	Pd (0.04-0.08)	0.1	0.4
17	0.08	0.18	0.03	0.015	0.2	...	...	Pd (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	Pd (0.04-0.08),	0.1	0.4
19	0.05	0.12	0.03	0.02	0.3	3.0-4.0	7.5-8.5	Mo (3.5-4.5), Cr (5.5-6.5), Zr (3.5-4.5)	0.15	0.4
20	0.05	0.12	0.03	0.02	0.3	3.0-4.0	7.5-8.5	Pd (0.04-0.08), Mo (3.5-4.5), Cr (5.5-6.5), Zr (3.5-4.5)	0.15	0.4
21	0.05	0.17	0.03	0.015	0.4	2.5-3.5	...	Mo (14.0-16.0), Cb (2.2-3.2), Si (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	0.2	0.05	0.015	0.4	5.5-6.75	3.5-4.5	Pd (0.04-0.08)	0.1	0.4
25	0.08	0.2	0.05	0.015	0.4	5.5-6.75	3.5-4.5	Pd (0.04-0.08), Ni (0.3-0.8)	0.1	0.4
26	0.08	0.25	0.03	0.015	0.3	...	...	Ru (0.08-0.14)	0.1	0.4
26H	0.08	0.25	0.03	0.015	0.3	...	...	Ru (0.08-0.14)	0.1	0.4
27	0.08	0.18	0.03	0.015	0.2	...	...	Ru (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	Ru (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	Ru (0.08-0.14)	0.1	0.4
—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—
32	0.08	0.11	0.03	0.015	0.25	4.5-5.5	0.6-1.4	Mo (0.6-1.2), Zr (0.6-1.4), Sn (0.6-1.4), Si (0.06-0.14)	0.1	0.4
33	0.08	0.25	0.03	0.015	0.3	...	...	Pd (0.01-0.02), Ru (0.02-0.04), Ni (0.35-0.55), Cr (0.1-0.2)	0.1	0.4
34	0.08	0.35	0.05	0.015	0.3	...	...	Pd (0.01-0.02), Ru (0.02-0.04), Ni (0.35-0.55), Cr (0.1-0.2)	0.1	0.4
35	0.08	0.25	0.05	0.015	0.2-0.8	4.0-5.0	1.1-2.1	Mo (1.5-2.5), Si (0.2-0.4)	0.1	0.4
36	0.04	0.16	0.03	0.015	0.03	...	...	Cb (42.0-47.0)	0.1	0.4
37	0.08	0.25	0.03	0.015	0.3	1.0-2.0	...	...	0.1	0.4
38	0.08	0.2-0.3	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.*

C. **Tensile Requirements :-**

1. The tensile properties of the pipe, in the condition specified, shall conform to the room temperature requirements of Table 2.
2. Mechanical properties for other conditions may be established by written agreement between the manufacturer and the purchaser.

Table 2

Grade	Tensile Strength, min, ksi (MPa)	Yield Strength (0.2 % Offset), ksi (MPa)		Elongation 2 in. or 50 mm gage length, min %
		min.	max.	
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.*

D. Length :-

1. Pipe shall be furnished in lengths as specified in the purchase order. No pipe shall be under the specified length and not more than 1⁄4 in. (6.4 mm) over that specified.

E. Bending Test :-

1. Pipe 2 in. (51 mm) and under in nominal diameter, shall be capable of being bent cold through 90° around a cylindrical mandrel which is twelve times the nominal diameter of the pipe, without developing cracks.

F. Flattening Test :-

1. Seamless pipe shall be capable of withstanding, without cracking, flattening under a load applied gradually at room temperature until the distance between the load platens is H inches. H is calculated as follows:

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

where: H = Minimum flattened height, in. (mm),
t = nominal wall thickness, in. (mm) and,
D = nominal pipe diameter, in. (mm) (not pipe size), and
For Grades 1 , 2, 2H, 3, 7, 7H, 11, 13, 14, 16, 16H, and 26H:
e = 0.04 through 1 in. pipe size, and
e = 0.06 over 1 in. pipe size.

G. Hydrostatic Test :-

1. Each length of pipe shall withstand, without showing bulges, leaks, or other defects, an internal hydrostatic pressure that will produce in the pipe wall a stress of 50 % of the minimum specified yield strength at room temperature. This pressure shall be determined by the equation:

$$P = Set / (Ro - 0.4t) \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where: P = minimum hydrostatic test pressure, psi (or MPa),
S = allowable fiber stress of one-half the minimum yield strength, psi (or MPa),
t = wall thickness, in. (or mm),

Ro = outside tube radius, in. (or mm), and
E = 1.0 seamless pipe.

2. The maximum hydrostatic test pressure shall not exceed 2500 psi (17.2 MPa) for sizes 3 in. (76 mm) and under, or 2800 psi (19.3 MPa) for sizes over 3 in. (76 mm).
3. Hydrostatic pressure shall be maintained for not less than 5 s.
4. When requested by the purchaser and so stated in the order, pipe in sizes 14 in. (356 mm) in diameter and smaller, shall be tested to one and one-half times the specified working pressure, provided the fiber stress corresponding to those test pressures does not exceed one-half the minimum specified yield strength of the material, as determined by the equation given in Point G.1.
5. When one and one-half times the working pressure exceeds 2800 psi (19.3 MPa), the hydrostatic test pressure shall be a matter of agreement between the manufacturer and the purchaser.

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