ASTM B338 / ASME SB338

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

This specification covers the requirements for 28 grades of titanium and titanium alloy tubing intended for surface condensers, evaporators, and heat exchangers, as follows:

Grade 1—Unalloyed titanium,
Grade 2—Unalloyed titanium,
Grade 2H—Unalloyed titanium (Grade 2 with 58 ksi minimum UTS),
Grade 3—Unalloyed titanium,
Grade 7—Unalloyed titanium plus 0.12 to 0.25 % palladium,
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,
Grade 12—Titanium alloy (0.3 % molybdenum, 0.8 % nickel),
Grade 13—Titanium alloy (0.5 % nickel, 0.05 % ruthenium),
Grade 14—Titanium alloy (0.5 % nickel, 0.05 % ruthenium),
Grade 15—Titanium alloy (0.5 % nickel, 0.05 % ruthenium),
Grade 16—Unalloyed titanium plus 0.04 to 0.08 % palladium,
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,
Grade 18—Titanium alloy (3 % aluminum, 2.5 % vanadium) plus 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 30—Titanium alloy (0.3 % cobalt, 0.05 % palladium),
Grade 31—Titanium alloy (0.3 % cobalt, 0.05 % palladium),
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. Chemical Requirements :-

The titanium shall conform to the chemical requirements prescribed in Table 1.

Table 1

Grade	Composition, Weight Percent [A,B,C,D,E]																
	C, max.	O_2 max.	N, max.	H, max.	Fe max.	Al	V	Pd	Ru	Ni	Mo	Cr	Co	Cb	Si	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
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
7	0.08	0.25	0.03	0.015	0.3	—	—	0.12-0.25	—	—	—	—	—	—	—	0.1	0.4
7H	0.08	0.25	0.03	0.015	0.3	—	—	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	—	—	0.12-0.25	—	—	—	—	—	—	—	0.1	0.4
12	0.08	0.25	0.03	0.015	0.3	—	—	—	—	0.6-0.9	0.2-0.4	—	—	—	—	0.1	0.4
13	0.08	0.10	0.03	0.015	0.2	—	—	—	0.04-0.06	0.4-0.6	—	—	—	—	—	0.1	0.4
14	0.08	0.15	0.03	0.015	0.3	—	—	—	0.04-0.06	0.4-0.6	—	—	—	—	—	0.1	0.4
15	0.08	0.25	0.05	0.015	0.3	—	—	—	0.04-0.06	0.4-0.6	—	—	—	—	—	0.1	0.4
16	0.08	0.25	0.03	0.015	0.3	—	—	0.04-0.08	—	—	—	—	—	—	—	0.1	0.4
16H	0.08	0.25	0.03	0.015	0.3	—	—	0.04-0.08	—	—	—	—	—	—	—	0.1	0.4

17	0.08	0.18	0.03	0.015	0.2	—	—	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	0.3	—	—	—	0.08-0.14	—	—	—	—	—	—	0.1	0.4
26H	0.08	0.25	0.03	0.015	0.3	—	—	—	0.08-0.14	—	—	—	—	—	—	0.1	0.4
27	0.08	0.18	0.03	0.015	0.2	—	—	—	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	0.3	—	—	0.04-0.08	—	—	—	—	0.2-0.8	—	—	0.1	0.4
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
33	0.08	0.25	0.03	0.015	0.3	—	—	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	0.3	—	—	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	0.2-0.8	4.0-5.0	1.1-2.1	—	—	—	1.5-2.5	—	—	—	0.2-0.4	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	0.3	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.*

B. Tensile Requirements :-

The room temperature tensile properties of the tube in the condition normally supplied shall conform to the requirements prescribed in Table 2.

Table 2

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
2H[A,B,C]	58	400	40	275	65	450	20
3[A]	65	450	55	380	80	550	18
7[A]	50	345	40	275	65	450	20
7H[A,B,C]	58	400	40	275	65	450	20
9[D]	125	860	105	725	...	...	10
9[A]	90	620	70	483	...	...	15[E]
11[A]	35	240	20	138	45	310	24
12[A]	70	483	50	345	...	...	18[E]
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
16H[A,B,C]	58	400	40	275	65	450	20
17[A]	35	240	20	138	45	310	24
18[D]	125	860	105	725	...	...	10
18[A]	90	620	70	483	...	...	15[E]

26	50	345	40	275	65	450	20
26H[A,B,C]	58	400	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
38	130	895	115	794	...	...	10

[A] *Properties for material in the annealed condition.*

[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, 1 6H, 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, 1 6, and 26 test reports, where over 99 % met the 58 ksi minimum UTS.*

[D] *Properties for cold-worked and stress-relieved material.*

[E] *Elongation for welded tubing manufactured from continuously cold rolled and annealed strip from coils for Grades 9, 12, and 18 will be 12 %.*

C. <u>Flattening Test :-</u>

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:

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

where: H = the minimum flattened height, in. (mm),
t = the nominal wall thickness, in. (mm), and
D = the nominal tube diameter, in. (mm).

For Grades 1, 2, 2H, 7, 7H, 11, 13, 14, 16, 16H, 17, 26, 26H, 27, 30, and 33:

e = 0.07 in. for all diameters ....…… (2)

For Grade 3, 31, and 34:

e = 0.04 through 1 in. diameter …… (3)

e = 0.06 over 1 in. diameter …… (4)

For Grades 9, 12, 15, 18, 28, 35, 36, 37, and 38:

e shall be negotiated between the producer and the purchaser.

2. Welded tube shall be subjected to a reverse flattening test in accordance with Annex 2 of Test Methods and Definitions A370

D. Flaring Test :-

1. For tube 3(1⁄2) in. (88 mm) in outside diameter and smaller, and 0.134 in. (3.4 mm) in wall thickness and thinner, a section of tube approximately 4 in. (102 mm) in length shall withstand being flared with a tool having a 60° included angle until the tube at the mouth of the flare has been expanded in accordance with Table 3.
2. Flaring tests on larger diameter tube or tubing outside the range of Table 3 shall be as agreed upon between the manufacturer and the purchaser.

Table 3

Grade	Expansion of Inside Diameter,
1	22
2, 2H	20
3	17
7, 7H	20
9[A]	20
11	22
12	17
13	22
14	20
15	17
16, 16H	20
17	22
18[A]	20
26, 26H	20
27	22
28[A]	20
30	20
31	17
33	20
34	17
35	10
37	20
38	15

[A] Annealed.

E. Non-destructive Tests :-

1. Electromagnetic Testing.
2. Ultrasonic Testing.
3. Hydrostatic Test:
    i. Each tube so tested shall withstand, without showing bulges, leaks, or other defects, an internal hydrostatic pressure that will produce in the tube wall a stress of 50 % of the minimum specified yield strength at room temperature. This pressure shall be determined by the equation:

$$P = SEt / (R_o - 0.4t) \quad \ldots\ldots (5)$$

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),
R_o = outside tube radius, in. (or mm),
E = 0.85 welded tube, and
E = 1 .0 seamless and welded/cold worked tube.

    ii. 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. Hydrostatic pressure shall be maintained for not less than 5 s.
4. Pneumatic Test:
    i. Each tube so tested shall withstand an internal air pressure of 100 psi (0.69 MPa), minimum, for 5 s, minimum, without showing evidence of leakage. The test method used shall permit easy detection of any leakage by using the pressure differential method or by placing the tube under water.

F. Length :-

1. When tube is ordered cut to length, the length shall not be less than that specified, but a variation of 1⁄8 in. (3.2 mm) will be permitted on tube up to 24 ft (7.3 m) inclusive. For lengths over 24 ft (7.3 m), an additional over tolerance of 1⁄8 in. (3.2 mm) for each 10 ft (3.05 m) or fraction thereof shall be permissible up to 1⁄2 in. (13 mm) maximum.

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