



Standard Specification for Titanium and Titanium Alloy Seamless Pipe¹

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1. Scope

1.1 This specification covers the requirements for 26 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,
- 1.1.3 *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,
- 1.1.6 *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,
- 1.1.13 *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,
 - 1.1.22 *Grade 27*—Unalloyed titanium plus 0.08 to 0.14 % ruthenium,
 - 1.1.23 *Grade 28*—Titanium alloy (3 % aluminum, 2.5 % vanadium plus 0.08–0.14 % ruthenium),
 - 1.1.24 *Grade 29*—Titanium alloy (6 % aluminum, 4 % vanadium, extra low interstitial, ELI plus 0.08–0.14 % ruthenium),
 - 1.1.25 *Grade 33*—Titanium alloy (0.4% nickel, 0.015% palladium, 0.025% ruthenium, 0.15% chromium), and
 - 1.1.26 *Grade 34*—Titanium alloy (0.4% nickel, 0.015% palladium, 0.025% ruthenium, 0.15% chromium).
- 1.2 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are for information only.

2. Referenced Documents

2.1 ASTM Standards:

- A 370 Test Methods and Definitions for Mechanical Testing of Steel Products²
- E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications³
- E 120 Test Methods for Chemical Analysis of Titanium and Titanium Alloys⁴
- E 1409 Test Method for Determination of Oxygen in Titanium and Titanium Alloys by the Inert Gas Fusion Technique⁵
- E 1447 Test Method for Determination of Hydrogen in Titanium and Titanium Alloys by the Inert Gas Fusion Thermal Conductivity Method⁵

2.2 ANSI/ASME Standard:

- B 36.19M-1985 Stainless Steel Pipe⁶

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 Annual Book of ASTM Standards, Vol 01.03.

³ Annual Book of ASTM Standards, Vol 14.02.

⁴ Annual Book of ASTM Standards, Vol 03.05.

⁵ Annual Book of ASTM Standards, Vol 03.06.

⁶ Available from American National Standards Institute, 11 W. 42nd St., 13th Floor, New York, NY 10036.

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),

TABLE 1 Chemical Requirements^A

Element	Composition, %							
	Grade 1	Grade 2	Grade 3	Grade 5	Grade 7	Grade 9	Grade 11	Grade 12
Nitrogen, max	0.03	0.03	0.05	0.05	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
Hydrogen, ^{B,C} max	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
Iron, max	0.20	0.30	0.30	0.40	0.30	0.25	0.20	0.30
Oxygen, max	0.18	0.25	0.35	0.20	0.25	0.15	0.18	0.25
Aluminum	...	...	...	5.5–6.75	...	2.5–3.5	...	...
Vanadium	...	...	...	3.5–4.5	...	2.0–3.0	...	...
Tin	...	...	...	...	...	...	...	...
Ruthenium	...	...	...	...	...	...	...	...
Palladium	...	...	...	...	0.12–0.25	...	0.12–0.25	...
Molybdenum	...	...	...	...	...	...	...	0.2–0.4
Chromium	...	...	...	...	...	...	...	...
Nickel	...	...	...	...	...	...	...	0.6–0.9
Niobium	...	...	...	...	...	...	...	...
Zirconium	...	...	...	...	...	...	...	...
Silicon	...	...	...	...	...	...	...	...
Residuals, ^{D,E,F} max each	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Residuals, ^{D,E,F} max total	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

Element	Composition, %							
	Grade 13	Grade 14	Grade 15	Grade 16	Grade 17	Grade 18	Grade 19	Grade 20
Nitrogen, max	0.03	0.03	0.05	0.03	0.03	0.03	0.03	0.03
Carbon, max	0.08	0.08	0.08	0.08	0.08	0.08	0.05	0.05
Hydrogen, ^{B,C} max	0.015	0.015	0.015	0.015	0.015	0.015	0.02	0.02
Iron, max	0.20	0.30	0.30	0.30	0.20	0.25	0.30	0.30
Oxygen, max	0.10	0.15	0.25	0.25	0.18	0.15	0.12	0.12
Aluminum	...	...	...	...	...	2.5–3.5	3.0–4.0	3.0–4.0
Vanadium	...	...	...	...	...	2.0–3.0	7.5–8.5	7.5–8.5
Tin	...	...	...	...	...	...	...	...
Ruthenium	0.04–0.06	0.04–0.06	0.04–0.06	...	...	...	...	...
Palladium	...	...	...	0.04–0.08	0.04–0.08	0.04–0.08	...	0.04–0.08
Molybdenum	...	...	...	...	...	...	3.5–4.5	3.5–4.5
Chromium	...	...	...	...	...	...	5.5–6.5	5.5–6.5
Nickel	0.4–0.6	0.4–0.6	0.4–0.6	...	...	...	...	...
Niobium	...	...	...	...	...	...	...	...
Zirconium	...	...	...	...	...	...	3.5–4.5	3.5–4.5
Silicon	...	...	...	...	...	...	...	...
Residuals, ^{D,E,F} max each	0.1	0.1	0.1	0.1	0.1	0.1	0.15	0.15
Residuals, ^{D,E,F} max total	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

Element	Composition, %									
	Grade 21	Grade 23	Grade 24	Grade 25	Grade 26	Grade 27	Grade 28	Grade 29	Grade 33	Grade 34
Nitrogen, max	0.03	0.03	0.05	0.05	0.03	0.03	0.03	0.03	0.03	0.05
Carbon, max	0.05	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Hydrogen, ^{B,C} max	0.015	0.0125	0.015	0.0125	0.015	0.015	0.015	0.015	0.015	0.015
Iron, max	0.40	0.25	0.40	0.40	0.30	0.20	0.25	0.25	0.30	0.30
Oxygen, max	0.17	0.13	0.20	0.20	0.25	0.18	0.15	0.13	0.25	0.35
Aluminum	2.5–3.5	5.5–6.5	5.5–6.75	5.5–6.75	...	...	2.5–3.5	5.5–6.5	...	...
Vanadium	...	3.5–4.5	3.5–4.5	3.5–4.5	...	...	2.0–3.0	3.5	...	...
Tin _{4.5}	...	...	...	...	...	...	...	...	...	...
Ruthenium	...	...	...	...	0.08–0.14	0.08–0.14	0.08–0.14	0.08–0.14	0.02–0.04	0.02–0.04
Palladium	...	...	0.04–0.08	0.04–0.08	...	...	...	...	0.01–0.02	0.01–0.02
Molybdenum	14.0–16.0	...	...	...	...	...	...	...	...	...
Chromium	...	...	...	...	...	...	...	...	0.1–0.2	0.1–0.2
Nickel	...	...	...	0.3–0.8	...	...	...	...	0.35–0.55	0.35–0.55

Element	Grade 21	Grade 23	Grade 24	Grade 25	Grade 26	Grade 27	Grade 28	Grade 29	Grade 33	Grade 34
Niobium	2.2–3.2	...	...	...	...	...	...	...	...	...
Zirconium	...	...	...	...	...	...	...	...	...	...
Silicon	0.15–0.25	...	...	...	...	...	...	...	...	...
Residuals, ^{D,E,F} max each	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Residuals, ^{D,E,F} max total	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Titanium ^G	balance	balance	balance	balance	balance	balance	balance	balance	Remainder	Remainder

^AAnalysis shall be completed for all elements listed in this table for each grade. The analysis results for the elements not quantified in the table need not be reported unless the concentration level is greater than 0.1 % each or 0.4 % total.

^BLower hydrogen may be obtained by negotiation with the supplier.

^CFinal product analysis.

^DNeed not be reported.

^EA 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.

^FThe purchaser may, in his written purchase order, request analysis for specific residual elements not listed in this specification.

^GThe percentage of titanium is determined by difference.

- 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, and Grade 29 alloys may be supplied in the following conditions:

5.2.1.1 *Grade 5, Grade 23, Grade 24, Grade 25, or Grade 29—annealed or aged condition,*

5.2.1.2 *Grade 9, Grade 18, or Grade 28—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*

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 of the limits specified in Table 1 for the applicable grade.

8. Tensile Requirements

8.1 The tensile properties of the pipe, in the condition specified, shall conform to the room temperature requirements of Table 5. Mechanical properties for other conditions may be established by written agreement between the manufacturer and the purchaser.

9. Permissible Variations in Dimensions

9.1 A system of standard pipe sizes approved by ANSI as American National Standard for Stainless Steel Pipe (ANSI/

TABLE 2 Dimensions of Pipe

NOTE 1—Schedule sizes conform to ANSI/ASME B36.19 (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	
			in	mm	in	mm	in	mm	in	mm	in	mm	in	mm	in	mm	in	mm
1/8	0.405	10.29	x	x	x	x	0.049	1.24	0.049	1.24	0.068	1.73	0.068	1.73	0.095	2.41	0.095	2.41
1/4	0.540	13.72	x	x	x	x	0.065	1.65	0.065	1.65	0.088	2.24	0.088	2.24	0.119	3.02	0.119	3.02
3/8	0.675	17.15	x	x	x	x	0.065	1.65	0.065	1.65	0.091	2.31	0.091	2.31	0.126	3.20	0.126	3.20
1/2	0.840	21.34	0.065	1.65	0.065	1.65	0.083	2.11	0.083	2.11	0.109	2.77	0.109	2.77	0.147	3.73	0.147	3.73
3/4	1.050	26.67	0.065	1.65	0.065	1.65	0.083	2.11	0.083	2.11	0.113	2.87	0.113	2.87	0.154	3.91	0.154	3.91
1	1.315	33.40	0.065	1.65	0.065	1.65	0.109	2.77	0.109	2.77	0.133	3.38	0.133	3.38	0.179	4.55	0.179	4.55
1-1/4	1.660	42.16	0.065	1.65	0.065	1.65	0.109	2.77	0.109	2.77	0.140	3.56	0.140	3.56	0.191	4.85	0.191	4.85
1-1/2	1.900	48.26	0.065	1.65	0.065	1.65	0.109	2.77	0.109	2.77	0.145	3.68	0.145	3.68	0.200	5.08	0.200	5.08
2	2.375	60.32	0.065	1.65	0.065	1.65	0.109	2.77	0.109	2.77	0.154	3.91	0.154	3.91	0.218	5.54	0.218	5.54
2-1/2	2.875	73.02	0.083	2.11	0.083	2.11	0.120	3.05	0.120	3.05	0.203	5.16	0.203	5.16	0.276	7.01	0.276	7.01
3	3.500	88.90	0.083	2.11	0.083	2.11	0.120	3.05	0.120	3.05	0.216	5.49	0.216	5.49	0.300	7.62	0.300	7.62
3-1/2	4.000	101.60	0.083	2.11	0.083	2.11	0.120	3.05	0.120	3.05	0.226	5.74	0.226	5.74	0.318	8.08	0.318	8.08
4	4.500	114.30	0.083	2.11	0.083	2.11	0.120	3.05	0.120	3.05	0.237	6.02	0.237	6.02	0.337	8.56	0.337	8.56
5	5.563	141.30	0.109	2.77	0.109	2.77	0.134	3.40	0.134	3.40	0.258	6.55	0.258	6.55	0.375	9.53	0.375	9.53
6	6.625	168.27	0.109	2.77	0.109	2.77	0.134	3.40	0.134	3.40	0.280	7.11	0.280	7.11	0.432	10.97	0.432	10.97
8	8.625	219.07	0.109	2.77	0.109	2.77	0.148	3.76	0.148	3.76	0.322	8.18	0.322	8.18	0.500	12.70	0.500	12.70
10	10.75	273.05	0.134	3.40	0.134	3.40	0.165	4.19	0.165	4.19	0.365	9.27	0.365	9.27	0.500	12.70	0.594	15.09
12	12.75	323.85	0.156	3.96	0.156	3.96	0.180	4.57	0.180	4.57	0.375	9.53	0.406	10.31	0.500	12.70	0.688	17.48
14	14.00	355.60	0.156	3.96	0.156	3.96	0.188	4.78	0.250	6.35	x	x	0.438	11.13	x	x	0.750	19.05
16	16.00	406.40	0.165	4.19	0.165	4.19	0.188	4.78	0.250	6.35	x	x	0.500	12.70	x	x	0.844	21.44
18	18.00	457.20	0.165	4.19	0.165	4.19	0.188	4.78	0.250	6.35	x	x	0.562	14.27	x	x	0.938	23.83
20	20.00	508.00	0.188	4.78	0.188	4.78	0.218	5.54	0.250	6.35	x	x	0.594	15.09	x	x	1.031	26.19
22	22.00	558.80	0.188	4.78	0.188	4.78	0.218	5.54	0.250	6.35	x	x	x	x	x	x	1.125	28.58
24	24.00	609.60	0.218	5.54	0.218	5.54	0.250	6.35	0.250	6.35	x	x	0.688	17.48	x	x	1.219	30.96
26	26.00	660.40	x	x	x	x	x	x	0.312	7.92	x	x	x	x	x	x	x	x
28	28.00	711.20	x	x	x	x	x	x	0.312	7.92	x	x	x	x	x	x	x	x
30	30.00	762.00	0.250	6.35	0.250	6.35	0.312	7.92	0.312	7.92	x	x	x	x	x	x	x	x
32	32.00	812.80	x	x	x	x	x	x	0.312	7.92	x	x	0.688	17.48	x	x	x	x
34	34.00	863.60	x	x	x	x	x	x	0.312	7.92	x	x	0.688	17.48	x	x	x	x
36	36.00	914.40	x	x	x	x	x	x	0.312	7.92	x	x	0.750	19.05	x	x	x	x

^AThreading 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)

^ANPS = nominal pipe size.

TABLE 4 Permissible Variations in Product Analysis

Element	Product Analysis Limits, Permissible Variation	
	max or Range, %	in Product Analysis
Nitrogen	0.05	+ 0.02
Carbon	0.10	+ 0.02
Hydrogen	0.02	+ 0.002
Iron	0.50	+ 0.15
Oxygen	0.30	+ 0.03
Oxygen	0.31 to 0.40	± 0.04
Aluminum	2.5 to 6.75	± 0.40
Vanadium	2.0 to 4.5	± 0.15
Vanadium	7.5 to 8.5	± 0.40
Palladium	0.01 to 0.02	± 0.002
Palladium	0.04 to 0.08	± 0.005
Palladium	0.12 to 0.25	± 0.02
Silicon	0.15 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
Zirconium	3.5 to 4.5	± 0.20
Chromium	0.1 to 0.2	± 0.02
Chromium	5.5 to 6.5	± 0.30
Niobium	2.2 to 3.2	± 0.15
Molybdenum	0.2 to 0.4	± 0.03
Molybdenum	3.5 to 4.5	± 0.20
Molybdenum	14.0 to 16.0	± 0.50
Nickel	0.3 to 0.9	± 0.05
Residuals ^A (each)	0.15	+ 0.02

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

ASME B36.19M-1985) reproduced as Table 2 shall apply.

9.2 *Diameter*—Variations in outside diameter shall not exceed those prescribed in Table 3.

9.3 *Thickness*—The variation in thickness at any point shall not be more than ±12.5 % of the nominal wall thickness specified.

9.4 *Length*—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.

9.5 *Straightness*—The pipe shall be free of kinks and bends and the maximum bow of lengths up to 10 ft (3 m) shall not exceed 1:500. For lengths greater than 10 ft, the maximum bow shall not exceed 1:400.

10. Finish

10.1 The finished pipe shall have smooth ends, be free of burrs, and shall be free of injurious external and internal imperfections of a nature that will interfere with the purpose for which it is intended. Minor defects may be removed providing the dimensional tolerances of Section 9 are not exceeded. Unless otherwise specified, the pipe shall be furnished free of scale.

11. Number of Tests

11.1 Samples for test shall be taken from one pipe for each 1000 ft (300 m), but in no case shall less than one pipe be tested, selected at random, from each lot. Results of the following tests shall be reported to the purchaser or his representative.

11.1.1 One tension test from each pipe selected.

11.1.2 The flattening test specified in 15.1.

11.1.3 The bend test, required by 14.1, when specified by the purchaser.

11.2 If any test specimen shows defective machining or develops flaws due to the preparation, the specimen may be discarded and another substituted.

11.3 If the percentage of elongation of any tension test specimen is less than that specified in 8.1, and any part of the fracture is more than 3/4 in. (19 mm) from the center of the gage length as indicated by scratches marked on the specimen being testing, the specimen may be discarded and another substituted.

11.4 Each length of pipe shall be subjected to the hydrostatic test specified in 16.1 and 16.2.

12. Retests

12.1 If the chemical or mechanical test results of any lot are not in conformance with the requirements of this specification, the lot may be retested at the option of the manufacturer. The frequency of the retest will be double the initial number of tests. If the results of the retest conform to the specification, then the retest values will become the test values for certification. Only original conforming test results or conforming retest results shall be reported to the purchaser. If the results for the retest fail to conform to the specification, the material will be rejected in accordance with Section 20.

13. Test Specimens and Methods of Testing

13.1 The test specimens and the tests required by this specification shall conform to those described in Test Methods and Definitions A 370.

13.2 All routine mechanical tests shall be made at room temperature.

13.3 The methods of analysis used shall be in accordance with Test Methods E 120, E 1409 and E 1447, as applicable, or as agreed upon between the manufacturer and the purchaser.

14. Bending Test

14.1 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.

14.1.1 Grade 5, Grade 23, Grade 24, Grade 25, and Grade 29 are exempt from this requirement.

15. Flattening Test

15.1 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:

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

TABLE 5 Tensile Requirements^A

Grade	Tensile Strength, min		Yield Strength (0.2 % Offset)				Elongation 2 in. or 50 mm
			min.		max.		
	ksi	(MPa)	ksi	(MPa)	ksi	(MPa)	gage length, min %
1	35	(240)	25	(170)	45	(310)	24
2	50	(345)	40	(275)	65	(450)	20
3	65	(450)	55	(380)	80	(550)	18
5	130	(895)	120	(828)	...	...	10
5 ^B	160	(1103)	150	(1034)	...	...	6
7	50	(345)	40	(275)	65	(450)	20
9	90	(620)	70	(483)	...	...	15
9 ^C	90	(620)	70	(483)	...	...	12
9 ^D	125	(860)	105	(725)	...	...	10
11	35	(240)	25	(170)	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
17	35	(240)	25	(170)	45	(310)	24
18	90	(620)	70	(483)	...	...	15
18 ^C	90	(620)	70	(483)	...	...	12
18 ^D	125	(860)	105	(725)	...	...	10
19 ^E	115	(793)	110	(759)	...	...	15
19 ^B	135	(930)	130	(897)	159	(1096)	10
19 ^F	165	(1138)	160	(1103)	185	(1276)	5
20 ^E	115	(793)	110	(759)	...	...	15
20 ^B	135	(930)	130	(897)	159	(1096)	10
20 ^F	165	(1138)	160	(1103)	185	(1276)	5
21 ^E	115	(793)	110	(759)	...	...	15
21 ^B	140	(966)	130	(897)	159	(1096)	15
21 ^F	170	(1172)	160	(1103)	185	(1276)	8
23	120	(828)	110	(759)	...	...	10
23 ^C	120	(828)	110	(759)	...	...	7.5 ^G , 6.0 ^H
24	130	(895)	120	(828)	...	...	10
25	130	(895)	120	(828)	...	...	10
26	50	(345)	40	(275)	65	(450)	20
27	35	(240)	25	(170)	45	(310)	24
28	90	(620)	70	(483)	...	...	15
28 ^C	90	(620)	70	(483)	...	...	12
28 ^D	125	(860)	105	(725)	...	...	10
29	120	(828)	110	(759)	...	...	10
29 ^C	120	(828)	110	(759)	...	...	7.5 ^G , 6.0 ^H
33	50	(345)	40	(275)	65	450	20
34	65	(450)	55	(380)	80	550	18

^A Properties for annealed condition except as noted.

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

^C Properties for material in transformed-beta condition.

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

^E Properties for solution-treated condition.

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

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

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

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, 3, 7, 11, 13, 14 and 16:
- e = 0.04 through 1 in. pipe size, and
- e = 0.06 over 1 in. pipe size.

For grades not shown above, the requirements for the flattening test shall be negotiated between the manufacturer and purchaser.

15.1.1 When low D-to-t ratio tubular products are tested, because the strain imposed due to geometry is unreasonably high on the inside surface at the six and twelve o'clock locations, cracks at these locations shall not be cause for rejection if the D-to-t ratio is less than ten (10).

15.2 All calculations are rounded to two decimal places. Examination for cracking shall be by the unaided eye.

16. Hydrostatic Test

16.1 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:

$$P = SEt/(R_o - 0.4t) \quad (2)$$

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

16.2 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). Hydrostatic pressure shall be maintained for not less than 5 s. 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 16.1. 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.

17. Referee Test and Analysis

17.1 In the event of disagreement between the manufacturer and the purchaser on the conformance of the material to the requirements of this specification, a mutually acceptable referee shall perform the tests in question. The referee's testing shall be used in determining conformance of this material to this specification.

18. Rounding-Off Procedure

18.1 For purposes of determining conformance with the specifications contained herein, an observed or a calculated value shall be rounded off to the nearest unit in the last right-hand significant digit used in expressing the limiting value. This is in accordance with the round-off method of Practice E 29.

19. Inspection

19.1 All tests and inspection shall be made prior to shipment and at the manufacturer's expense unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works. When specified in the order, the manufacturer shall notify the purchaser in time so that the purchaser may have his inspector present to witness any part of the tests that may be desired.

20. Rejection

20.1 Material not conforming to this specification or to authorized modifications shall be subject to rejection. Unless otherwise specified, rejected materials may be returned to the manufacturer at the manufacturer's expense, unless the purchaser receives, within three weeks of notice of rejection, other instructions for disposition.

21. Certification

21.1 If so requested by the purchaser, the manufacturer shall supply to the purchaser or his representative at least one copy of his report certifying that the material supplied has been inspected and tested in accordance with the requirements of this specification and that the results of chemical analysis and mechanical tests meet the requirements of this specification for the appropriate grade.

21.2 A certification shall be the basis of the acceptance of the material and shall state that the material conforms to the requirements of this specification. The manufacturer shall report in the certification the results of the chemical analyses and mechanical tests made in accordance with this specification.

22. Product Marking

22.1 Each length of pipe $\frac{3}{8}$ in. (9.5 mm) nominal diameter and larger, manufactured in accordance with this specification, shall be legibly marked, either by stenciling, stamping or rolling the following data:

- 22.1.1 Manufacturer's private identification mark,
- 22.1.2 ASTM designation and revision date,
- 22.1.3 Grade of titanium,
- 22.1.4 Pipe size and schedule, and
- 22.1.5 Ingot and lot number.

22.2 On smaller than $\frac{3}{8}$ in. (9.5 mm) nominal diameter pipe which is bundled, the same information may be legibly stamped on a metal tag securely attached to each bundle.

23. Packaging

23.1 The pipe shall be packaged in agreement with the manufacturer's standard practice, unless otherwise agreed to between the manufacturer and purchaser and so stated in the purchase order.

24. Keywords

24.1 pipe; seamless pipe; titanium; titanium alloy

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