Designation: B 862 – 06b$^{\epsilon 1}$

Standard Specification for Titanium and Titanium Alloy Welded Pipe[1]

This standard is issued under the fixed designation B 862; 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.

ε[1] NOTE—Tensile strength for Grade 5 in Table 4 was corrected editorially in March 2007.

1. Scope

1.1 This specification covers the requirements for 33 grades of titanium and titanium alloy welded 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 with extra low interstitial elements (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 37*—Titanium alloy (1.5 % aluminum), and

1.1.29 *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] 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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1.2 Pipe 8 in. NPS (nominal pipe size) and larger is most frequently custom made for an order. In such cases, the purchaser carefully should consider the applicability of this specification. Since the pipe is custom made, the purchaser may choose a wall thickness other than those in Table 1 to meet specific operating conditions. The purchaser may also be better served to specify only the portions of this specification that are required to meet the operating conditions (for example, annealing, flattening test, chemistry, properties, etc.).

1.3 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.

1.4 Optional supplementary requirements are provided for pipe where a greater degree of testing is desired. These supplementary requirements may be invoked by the purchaser, when desired, by specifying in the order.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products

B 600 Guide for Descaling and Cleaning Titanium and Titanium Alloy Surfaces

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 120 Test Methods for Chemical Analysis of Titanium and Titanium Alloys[3]

E 1409 Test Method for Determination of Oxygen and Nitrogen in Titanium and Titanium Alloys by the Inert Gas Fusion Technique

E 1417 Practice for Liquid Penetrant Testing

E 1447 Test Method for Determination of Hydrogen in Titanium and Titanium Alloys by the Inert Gas Fusion Thermal Conductivity/Infrared Detection Method

2.2 *ANSI/ASME Standards:* [4]

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

ASME Boiler and Pressure Vessel Code, Section VIII

2.3 *AWS Standard:* [5]

AWS A5.16/A5.16M-2004 Specification for Titanium and Titanium Alloy Welding Electrodes and Rods

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 *welded pipe*, *n*—a hollow tubular product produced by forming flat-rolled product and seam welding to make a right circular cylinder.

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 2),

4.1.3 Nominal pipe size and schedule (Table 1),

4.1.4 Diameter tolerance (see 9.2),

4.1.5 Method of manufacture and finish (Sections 5 and 10),

4.1.6 Product analysis, if required (Sections 6 and 7; Table 1 and Table 3),

4.1.7 Mechanical properties, (Sections 8, 11, 13, 14, and 15, and Table 4),

4.1.8 Packaging (Section 22),

4.1.9 Inspection and test reports (Sections 18, 19 and 20), and

4.1.10 Supplementary requirements.

5. Manufacture

5.1 Welded pipe shall be made from annealed flat-rolled products by a welding process that will yield a product meeting the requirements of this specification. Filler metal, if used, shall be of the grade shown in Table 5.

5.1.1 Welded pipe may be further reduced by cold working or hot working. Cold reduced pipe shall be annealed after cold working at a temperature of not less than 1000°F. Hot worked pipe finished above 1400°F (760°C) need not be further heat treated.

5.2 Pipe shall be furnished as follows unless otherwise specified:

5.2.1 Grades 1, 2, 2H, 7, 7H, 11, 13, 14, 16, 16H, 17, 26H, 33, and 37 shall be furnished as welded or annealed.

5.2.2 Grades 3, 12, 15, and 34 shall be furnished as annealed.

5.2.3 Grade 5, Grade 23, Grade 24, Grade 25, or Grade 35 shall be furnished as annealed, or aged.

5.2.4 Grade 9, Grade 18, or Grade 38 shall be furnished as annealed.

5.2.5 Grade 19, Grade 20, or Grade 21 shall be furnished as solution treated, or solution treated and aged.

6. Chemical Composition

6.1 The grades of titanium and titanium alloy metal covered by this specification shall conform to the requirements of the chemical compositions shown in Table 2.

6.1.1 The elements listed in Table 2 are intentional alloy additions or elements that are inherent to the manufacture of titanium sponge, ingot, or mill product.

6.1.1.1 Elements other than those listed in Table 2 are deemed to be capable of occurring in the grades listed in Table 2 by and only by way of unregulated or unanalyzed scrap additions to the ingot melt. Therefore, product analysis for

[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] Withdrawn.

[4] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

[5] Available from American Welding Society (AWS), 550 NW LeJeune Rd., Miami, FL 33126.

TABLE 1 Dimensions of Pipe

NOTE 1—Schedule sizes conform to ANSI/ASME B 36.19 (for "S" sizes) or B 36.10 (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															
			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	in	mm
⅛	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
¼	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
⅜	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
½	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
¾	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
1-¼	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
1-½	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
2-½	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
3-½	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

[A] Threading not permitted in accordance with ANSI B.1.20.1.

TABLE 2 Chemical Requirements[A]

Element	Composition, %										
	Grade 1	Grade 2	Grade 2H	Grade 3	Grade 5	Grade 7	Grade 7H	Grade 9	Grade 11	Grade 12	Grade 13
Nitrogen, max	0.03	0.03	0.03	0.05	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	0.08	0.08
Hydrogen,[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
Iron, max	0.20	0.30	0.30	0.30	0.40	0.30	0.30	0.25	0.20	0.30	0.20
Oxygen, max	0.18	0.25	0.25	0.35	0.20	0.25	0.25	0.15	0.18	0.25	0.10
Aluminum	...	...	...	...	5.5–6.75	...	...	2.5–3.5	...	...	...
Vanadium	...	...	...	...	3.5–4.5	...	...	2.0–3.0	...	...	...
Tin	...	...	...	...	...	...	...	...	...	...	...
Ruthenium	...	...	...	...	...	...	...	...	...	...	0.04–0.06
Palladium	...	...	...	...	...	0.12–0.25	0.12–0.25	...	0.12–0.25	...	...
Cobalt	...	...	...	...	...	...	...	...	...	...	...
Molybdenum	...	...	...	...	...	...	...	...	...	0.2–0.4	...
Chromium	...	...	...	...	...	...	...	...	...	...	...
Nickel	...	...	...	...	...	...	...	...	...	0.6–0.9	0.4–0.6
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	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	0.4
Titanium[G]	balance	balance	balance	balance	balance	balance	balance	balance	balance	balance	balance

Element	Composition, %										
	Grade 14	Grade 15	Grade 16	Grade 16H	Grade 17	Grade 18	Grade 19	Grade 20	Grade 21	Grade 23	Grade 24
Nitrogen, max	0.03	0.05	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.05
Carbon, max	0.08	0.08	0.08	0.08	0.08	0.08	0.05	0.05	0.05	0.08	0.08
Hydrogen,[B,C] max	0.015	0.015	0.015	0.015	0.015	0.015	0.02	0.02	0.015	0.0125	0.015
Iron, max	0.30	0.30	0.30	0.30	0.20	0.25	0.30	0.30	0.40	0.25	0.40
Oxygen, max	0.15	0.25	0.25	0.25	0.18	0.15	0.12	0.12	0.17	0.13	0.20
Aluminum	...	...	...	...	...	2.5–3.5	3.0–4.0	3.0–4.0	2.5–3.5	5.5–6.5	5.5–6.75
Vanadium	...	...	...	...	...	2.0–3.0	7.5–8.5	7.5–8.5	...	3.5–4.5	3.5–4.5
Tin	...	...	...	...	...	...	...	...	...	...	...
Ruthenium	0.04–0.06	0.04–0.06	...	...	...	...	...	...	...	...	...
Palladium	...	...	0.04–0.08	0.4–0.08	0.04–0.08	0.04–0.08	...	0.04–0.08	...	...	0.04–0.08
Cobalt	...	...	...	...	...	...	...	...	...	...	...
Molybdenum	...	...	...	...	...	...	3.5–4.5	3.5–4.5	14.0–16.0	...	...
Chromium	...	...	...	...	...	...	5.5–6.5	5.5–6.5	...	...	...
Nickel	0.4–0.6	0.4–0.6	...	...	...	...	...	...	...	...	...
Niobium	...	...	...	...	...	...	...	...	2.2–3.2	...	...
Zirconium	...	...	...	...	...	...	3.5–4.5	3.5–4.5	...	...	...
Silicon	...	...	...	...	...	...	...	...	0.15–0.25	...	...
Residuals,[D,E,F] max each	0.1	0.1	0.1	0.1	0.1	0.1	0.15	0.15	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	0.4
Titanium[G]	balance	balance	balance	balance	balance	balance	balance	balance	balance	balance	balance

Element	Composition, %										
	Grade 25	Grade 26	Grade 26H	Grade 27	Grade 28	Grade 29	Grade 33	Grade 34	Grade 35	Grade 37	Grade 38
Nitrogen, max	0.05	0.03	0.03	0.03	0.03	0.03	0.03	0.05	0.05	0.03	0.03
Carbon, max	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Hydrogen,[B,C] max	0.0125	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
Iron, max or range	0.40	0.30	0.30	0.20	0.25	0.25	0.30	0.30	0.20–0.80	0.30	1.2–1.8
Oxygen, max or range	0.20	0.25	0.25	0.18	0.15	0.13	0.25	0.35	0.25	0.25	0.20–0.30
Aluminum	5.5–6.75	...	...	...	2.5–3.5	5.5–6.5	...	...	4.0–5.0	1.0–2.0	3.5–4.5
Vanadium	3.5–4.5	...	...	...	2.0–3.0	3.5–4.5	...	...	1.1–2.1	...	2.0–3.0
Tin	...	...	...	...	...	...	...	...	...	...	...
Ruthenium	...	0.08–0.14	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	...	...	...	...	...	0.01-0.02	0.01-0.02	...	...	...
Cobalt	...	...	...	...	...	...	...	...	...	...	...
Molybdenum	...	...	...	...	...	...	...	...	1.5–2.5	...	...
Chromium	...	...	...	...	...	...	0.1-0.2	0.1-0.2	...	...	...
Nickel	0.3–0.8	...	...	...	...	...	0.35-0.55	0.35-0.55	...	...	...
Niobium	...	...	...	...	...	...	...	...	...	...	...

TABLE 2 *Continued*

Element	Composition, %										
	Grade 25	Grade 26	Grade 26H	Grade 27	Grade 28	Grade 29	Grade 33	Grade 34	Grade 35	Grade 37	Grade 38
Zirconium	...	...	...	...	...	...	...	...	...	...	...
Silicon	...	...	...	...	...	...	...	...	0.20–0.40	...	...
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	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	0.4
Titanium[G]	balance	balance	balance	balance	balance	balance	Remainder	Remainder	Remainder	Remainder	balance

[A] Analysis 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.
[B] Lower hydrogen may be obtained by negotiation with the manufacturer.
[C] Final product analysis.
[D] Need not be reported.
[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 his written purchase order, request analysis for specific residual elements not listed in this specification.
[G] The percentage of titanium is determined by difference.

TABLE 3 Permissible Variations in Product Analysis

Element	Product Analysis Limits, Max or Range, %	Permissible Variation 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
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.

elements not listed in Table 2 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 a 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 3 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 2 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 4. 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/ASME B 36.19M-1985) reproduced as Table 1 shall apply.

9.2 Permissible variations in dimensions at any point in the length of the pipe shall conform to the following:

9.2.1 Variations in outside diameter, unless otherwise specified, shall not exceed the limits prescribed in Table 6. For diameters greater than 30 in., the diameter shall not exceed ±0.5 % of the specified outside diameter. The tolerances on the outside diameter include ovality except as provided for in 9.2.2 and 9.2.3.

9.2.2 Thin-wall pipe usually develops significant ovality (out-of-roundness) during final annealing, straightening, or both. Thin-wall pipe are defined as having a wall thickness of 3 % or less of the outside diameter.

9.2.3 The diameter tolerances of Table 6 are not sufficient to provide for additional ovality expected in thin-wall pipe and are applicable only to the mean of the extreme (maximum and minimum) outside diameter readings in any one cross section. However, for thin-wall pipe the difference in extreme outside

TABLE 4 Tensile Requirements[A]

Grade	Tensile Strength, min		Yield Strength (0.2 % Offset)				Elongation 2 in. or 50 mm, gauge length, min %
			min		max		
	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
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
19[E]	115	(793)	110	(759)	...	...	15
19[D]	135	(930)	130	(897)	159	(1096)	10
19[D]	165	(1138)	160	(1103)	185	(1276)	5
20[E]	115	(793)	110	(759)	...	...	15
20[D]	135	(930)	130	(897)	159	(1096)	10
20[D]	165	(1138)	160	(1103)	185	(1276)	5
21[E]	115	(793)	110	(759)	...	...	15
21[D]	140	(966)	130	(897)	159	(1096)	15
21[D]	170	(1172)	160	(1104)	185	(1276)	8
23	120	(828)	110	(759)	...	...	10
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
29	120	(828)	110	(759)	...	...	10
33	50	(345)	40	(275)	65	(450)	20
34	65	(450)	55	(380)	80	(550)	18
35	130	(895)	120	(828)	...	...	5
37	50	(345)	31	(215)	65	(450)	20
38	130	(895)	115	(794)	...	...	10

[A] Properties for as welded or 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 material in the solution treated and aged condition.
[E] Properties for material in the solution treated condition.

† Tensile strength for Grade 3 was corrected editorially.
† Tensile strength for Grade 5 was corrected editorially.

diameter readings (ovality) in any one cross section shall not exceed 1.5 % of the specified outside diameter.

9.2.4 Straightness shall be determined by using a 10 ft (3 m) straight edge placed so that both ends of the straight edge are in contact with the pipe. The separation between the straight edge and the pipe shall not exceed 0.250 in. at any point.

9.2.5 Thickness of the wall shall be measured by any appropriate means. The variation in thickness at any point shall not be more than ±12.5 % of the nominal wall thickness specified, unless otherwise agreed upon between the purchaser and manufacturer at the time of the order. Maximum reinforcement of the weld shall conform to the values prescribed in Table 7.

9.2.6 *Length*—Pipe shall be furnished in lengths as specified in the purchase order. The length tolerance for pipe ordered in specified lengths of 24 ft or less shall be plus ¼ in. (6.4 mm) minus zero. Random lengths of pipe and lengths of pipe over 24 ft may be ordered and the maximum and minimum lengths supplied shall be specified in a purchase order.

10. Finish

10.1 The finished pipe shall be straight and shall have smooth ends, be free of burrs, and shall be free of injurious external and internal imperfections. Minor defects may be

TABLE 5 Permissible Filler Metal[A]

Base Metal	Filler Metal
Grade 1	ERTi–1
Grade 2	ERTi–2
Grade 2H	ERTi–2
Grade 3	ERTi-3
Grade 5	ERTi–5
Grade 7	ERTi–7
Grade 7H	ERTi–7
Grade 9	ERTi–9
Grade 11	ERTi–11
Grade 12	ERTi–12
Grade 13	ERTi–13
Grade 14	ERTi–14
Grade 15	ERTi–15
Grade 16	ERTi–16 or ERTi–7
Grade 16H	ERTi–16 or ERTi-7
Grade 17	ERTi–17 or ERTi–11
Grade 18	ERTi–18
Grade 19	Grade 19
Grade 20	Grade 20
Grade 21	Grade 21
Grade 23	ERTi–23
Grade 24	ERTi–24
Grade 25	ERTi–25
Grade 26	ERTi–26 or ERTi–7
Grade 26H	ERTi–26 or ERTi-7
Grade 27	ERTi–27 or ERTi–11
Grade 28	ERTi–28
Grade 29	ERTi–29
Grade 32	ERTi–32
Grade 33	ERTi–33
Grade 34	ERTi–34
Grade 35	Grade 35
Grade 38	Grade 38

[A] ERTi-XX Filler metal grades as listed in AWS A5.16/A5.16M-2004.

removed, providing the dimensional tolerances of 9.2.5 are not exceeded. Unless otherwise specified, the pipe shall be furnished free of scale.

11. Number of Tests

11.1 Tests shall be made as follows on 2 % of the process length pipes selected at random, from each lot, but in no case shall less than one pipe be tested. Results of the following tests shall be reported to the purchaser or their representative.

11.1.1 One tension test from each pipe selected.

11.1.2 The guided bend test or flattening test specified in 14.1 and 14.2.

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 ¾ in. (19 mm) from the center of the gauge length as indicated by scratches marked on the specimen before testing, the specimen may be discarded and another substituted.

11.4 Each length of pipe shall be subjected to the hydrostatic test specified in 15.1 and 15.2.

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 19.

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. Test specimens shall be cut from the welded pipe except as specified in 13.2.

13.2 For pipe sizes over 14 in. outside diameter, a prolongation made from the same heat of raw material and subjected to all welding and heat treatment procedures as the ordered pipe may be used for mechanical property testing instead of testing the ordered pipe.

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

13.4 For referee purposes, Test Methods A 370, E 8, E 120, E 1409, and E 1447 shall be used.

14. Pipe Weld Quality Tests

14.1 Assessment of pipe weld quality shall be performed by either the flattening test or the guided bend test. Test specimens shall be selected randomly from each lot of pipe manufactured. Test plates of the same material may be attached to the pipe and welded as prolongations of the pipe longitudinal seam. See Table 7.

14.1.1 *Guided Bend Test*—For Grades 1, 2, 2H, 7, 7H, 11, 13, 14, 16, 16H, 17, 26H, and 33 a longitudinal or transverse guided bend test of the weld shall be performed in accordance with the method outlined in the ASME Boiler and Pressure Vessel Code, Section VIII, Paragraph UNF-95. The ductility of the weld shall be considered acceptable when there is no evidence of cracks after bending in the weld or between the weld and the tube metal. Test specimens shall be randomly selected from the pipe manufactured in accordance with 13.1, 13.2, and 11.1.2.

14.1.2 For Grades 3, 5, 9, 12, 15, 18, 19, 20, 21, 23, 24, 25, 34, 35, 37, and 38 the requirements for the guided bend test shall be negotiated between the manufacturer and the purchaser.

14.2 *Flattening Test*—Welded pipe in the final condition 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. The weld shall be positioned at either 90° or 270° to the direction of the applied load. H is calculated as follows:

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

where:

H = minimum flattened height, in. (mm),
t = nominal wall thickness, in. (mm),
D = nominal pipe outside diameter, in. (mm) (not pipe size), and

For Grades 1, 2, 2H, 3, 7, 7H, 11, 13, 14, 16, 16H, 17, and 26H:

TABLE 6 Permissible Variations in Diameter

Nominal Outside Diameter (NPS)[A]	Permissible Variations in Outside Diameter	
	Over	Under
⅛ in. to 1½ in. (3.2 mm to 38 mm)	1/64 in. (0.397 mm)	1/32 in. (0.794 mm)
over 1½ 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)
over 18 in. to 26 in. (432 mm to 660 mm)	⅛ in. (3.175 mm)	1/32 in. (0.794 mm)
over 26 in. to 30 in. (660 mm to 762 mm)	5/32 in. (3.969 mm)	1/32 in. (0.794 mm)

[A] NPS = nominal pipe size.

TABLE 7 Maximum Weld Reinforcement

Actual Material Thickness, in.	Maximum Reinforcement, in. (mm)	
	Circumferential Joints in Pipe	Other Welds
Less than 3/32	3/32 (2.832)	1/32 (0.794)
3/32 to 3/16 , incl.	⅛ (3.175)	1/16 (1.588)
Over 3/16 to ½ , incl.	5/32 (3.969)	3/32 (2.832)
Over ½ to 1, incl.	3/16 (4.764)	3/32 (2.832)
Over 1 to 2, incl.	¼ (6.35)	⅛ (3.175)
Over 2 to 3, incl.	¼ (6.35)	5/32 (3.969)
Over 3 to 4, incl.	¼ (6.35)	7/32 (5.558)
Over 4 to 5, incl.	¼ (6.35)	¼ (6.35)
Over 5	5/16 (7.94)	5/16 (7.94)

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.

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

14.2.2 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. Hydrostatic Test

15.1 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 (MPa),
S = allowable fiber stress of one-half the minimum yield strength, psi (MPa),
t = wall thickness, in. (mm),
R_o = outside tube radius, in. (mm), and
E = 0.85 for welded pipe.

15.2 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 15.1. When one and one-half times the working pressure exceeds 2800 psi (19.3 MPa), the hydrostatic test pressure shall be as agreed upon between the manufacturer and the purchaser.

16. Referee Test and Analysis

16.1 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 the material to this specification.

17. Rounding-Off Procedure

17.1 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.

18. Inspection

18.1 All specified 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 purchaser inspection is 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 desired.

19. Rejection

19.1 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.

19.2 Each length of pipe received from the manufacturer may be inspected by the purchaser. Pipe not meeting the requirements of this specification or requirements specified in a purchase order may be rejected and the manufacturer shall be notified. Disposition of rejected material shall be as stated in 19.1.

20. Certification

20.1 If so requested by the purchaser, the manufacturer shall supply at least one copy of his report certifying that the material supplied has been manufactured, sampled, tested, and inspected 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.

20.2 A certification shall be the basis of 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, mechanical property tests, and any supplementary tests made in accordance with this specification. If mechanical property testing was performed on a prolongation as specified in 13.2, the width of the gauge length tested shall be reported in the certification.

21. Product Marking

21.1 Each length of pipe ⅜ 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:

21.1.1 Manufacturer's private identification mark,

21.1.2 ASTM designation and revision date,

21.1.3 Grade of titanium,

21.1.4 Pipe size and schedule,

21.1.5 Heat number and lot number, and

21.1.6 Heat treatment condition, for example, annealed (ANN), solution treated (ST), solution treated and aged (STA), stress relieved (SR), not heat treated (No HT).

21.2 On smaller than ⅜ in. (9.5 mm) nominal diameter pipe that is bundled, the same information may be stamped legibly on a metal tag securely attached to each bundle.

22. Packaging

22.1 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.

23. Keywords

23.1 pipe; titanium; titanium alloy; welded pipe

SUPPLEMENTARY REQUIREMENTS

One or more of the following supplementary requirements shall apply only when specified in the purchase order. Subject to agreement between the purchaser and manufacturer, retest and retreatment provisions of these supplementary requirements may be modified. The extent and quantity of tests to be performed shall be specified by the purchaser.

S1. Pipe Requiring Special Consideration

S1.1. *Liquid Penetrant Inspection:*

S1.1.1 Liquid penetrant inspection shall be performed on all weld surfaces on the outside diameter and a length up to 1.5 times the nominal diameter on the inside diameter weld. An acceptance standard shall be agreed upon between the purchaser and the manufacturer prior to acceptance of the order. At a minimum, procedures and acceptance shall meet the requirements of Practice E 1417. Evidence of S1.1.1 shall be required in the certification.

S1.2. *Radiographic Examination:*

S1.2.1 The entire length of weld in each welded pipe shall be examined radiographically, using x-radiation, in accordance with Paragraph UW-51 of Section VIII, Division 1 of the ASME Boiler and Pressure Vessel Code. In addition to the marking required by Section 21, each pipe shall be marked "RT" after the specification and grade. Evidence of S1.2.1 shall be required in the certification.

S1.2.2 Pipe welds shall be spot radiographed, using x-radiation, in accordance with Paragraph UW-52 of Section VIII, Division 1 of the ASME Boiler and Pressure Vessel Code. Evidence of S1.2.2 shall be required in the certification.

S1.3. *Stress Relief Heat Treatment:*

S1.3.1 The stress relieving heat treatment shall consist of holding the pipe at a minimum temperature of 1100°F for not less than 0.5 h/in. of wall thickness.

S1.3.2 Minimum time at temperature shall be 20 min. All stress relieved pipe shall be subsequently cleaned so as to be free of oxide scale in accordance with Guide B 600.