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Standard Specification for Titanium and Titanium Alloy Strip, Sheet, and Plate¹

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This standard has been approved for use by agencies of the Department of Defense.

^{ε1} NOTE—Specified thickness was corrected editorially from 0.02 to 0.012 in Table 9 in July 2009.

1. Scope*

1.1 This specification² covers annealed titanium and titanium alloy strip, sheet, and plate as follows:

- 1.1.1 *Grade 1*—Unalloyed titanium,
- 1.1.2 *Grade 2*—Unalloyed titanium,
 - 1.1.2.1 *Grade 2H*—Unalloyed titanium (Grade 2 with 58 ksi minimum UTS),
- 1.1.3 *Grade 3*—Unalloyed titanium,
- 1.1.4 *Grade 4*—Unalloyed titanium,
- 1.1.5 *Grade 5*—Titanium alloy (6 % aluminum, 4 % vanadium),
- 1.1.6 *Grade 6*—Titanium alloy (5 % aluminum, 2.5 % tin),
- 1.1.7 *Grade 7*—Unalloyed titanium plus 0.12 to 0.25 % palladium,
 - 1.1.7.1 *Grade 7H*—Unalloyed titanium plus 0.12 to 0.25 % palladium (Grade 7 with 58 ksi minimum UTS),
- 1.1.8 *Grade 9*—Titanium alloy (3.0 % aluminum, 2.5 % vanadium),
- 1.1.9 *Grade 11*—Unalloyed titanium plus 0.12 to 0.25 % palladium,
- 1.1.10 *Grade 12*—Titanium alloy (0.3 % molybdenum, 0.8 % nickel),
- 1.1.11 *Grade 13*—Titanium alloy (0.5 % nickel, 0.05 % ruthenium),
- 1.1.12 *Grade 14*—Titanium alloy (0.5 % nickel, 0.05 % ruthenium),
- 1.1.13 *Grade 15*—Titanium alloy (0.5 % nickel, 0.05 % ruthenium),
- 1.1.14 *Grade 16*—Unalloyed titanium plus 0.04 to 0.08 % palladium,

- 1.1.14.1 *Grade 16H*—Unalloyed titanium plus 0.04 to 0.08 % palladium (Grade 16 with 58 ksi minimum UTS),
- 1.1.15 *Grade 17*—Unalloyed titanium plus 0.04 to 0.08 % palladium,
- 1.1.16 *Grade 18*—Titanium alloy (3 % aluminum, 2.5 % vanadium) plus 0.04 to 0.08 % palladium,
- 1.1.17 *Grade 19*—Titanium alloy (3 % aluminum, 8 % vanadium, 6 % chromium, 4 % zirconium, 4 % molybdenum),
- 1.1.18 *Grade 20*—Titanium alloy (3 % aluminum, 8 % vanadium, 6 % chromium, 4 % zirconium, 4 % molybdenum) plus 0.04 % to 0.08 % palladium,
- 1.1.19 *Grade 21*—Titanium alloy (15 % molybdenum, 3 % aluminum, 2.7 % niobium, 0.25 % silicon),
- 1.1.20 *Grade 23*—Titanium alloy (6 % aluminum, 4 % vanadium with extra low interstitial elements, ELI),
- 1.1.21 *Grade 24*—Titanium alloy (6 % aluminum, 4 % vanadium) plus 0.04 % to 0.08 % palladium,
- 1.1.22 *Grade 25*—Titanium alloy (6 % aluminum, 4 % vanadium) plus 0.3 % to 0.8 % nickel and 0.04 % to 0.08 % palladium,
- 1.1.23 *Grade 26*—Unalloyed titanium plus 0.08 to 0.14 % ruthenium,
 - 1.1.23.1 *Grade 26H*—Unalloyed titanium plus 0.08 to 0.14 % ruthenium (Grade 26 with 58 ksi minimum UTS),
- 1.1.24 *Grade 27*—Unalloyed titanium plus 0.08 to 0.14 % ruthenium,
- 1.1.25 *Grade 28*—Titanium alloy (3 % aluminum, 2.5 % vanadium) plus 0.08 to 0.14 % ruthenium,
- 1.1.26 *Grade 29*—Titanium alloy (6 % aluminum, 4 % vanadium with extra low interstitial elements, ELI) plus 0.08 to 0.14 % ruthenium,
- 1.1.27 *Grade 30*—Titanium alloy (0.3 % cobalt, 0.05 % palladium),
- 1.1.28 *Grade 31*—Titanium alloy (0.3 % cobalt, 0.05 % palladium),
- 1.1.29 *Grade 32*—Titanium alloy (5 % aluminum, 1 % tin, 1 % zirconium, 1 % vanadium, 0.8 % molybdenum),
- 1.1.30 *Grade 33*—Titanium alloy (0.4 % nickel, 0.015 % palladium, 0.025 % ruthenium, 0.15 % chromium),

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 For ASME Boiler and Pressure Vessel Code applications see related Specifications SB-265 in Section II of that Code.

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

1.1.31 *Grade 34*—Titanium alloy (0.4 % nickel, 0.015 % palladium, 0.025 % ruthenium, 0.15 % chromium),

1.1.32 *Grade 35*—Titanium alloy (4.5 % aluminum, 2 % molybdenum, 1.6 % vanadium, 0.5 % iron, 0.3 % silicon),

1.1.33 *Grade 36*—Titanium alloy (45 % niobium),

1.1.34 *Grade 37*—Titanium alloy (1.5 % aluminum), and

1.1.35 *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.

1.2 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

2. Referenced Documents

2.1 ASTM Standards:³

E8 Test Methods for Tension Testing of Metallic Materials

E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

E290 Test Methods for Bend Testing of Material for Ductility

E539 Test Method for X-Ray Fluorescence Spectrometric Analysis of 6Al-4V Titanium Alloy

E1409 Test Method for Determination of Oxygen and Nitrogen in Titanium and Titanium Alloys by the Inert Gas Fusion Technique

E1447 Test Method for Determination of Hydrogen in Titanium and Titanium Alloys by Inert Gas Fusion Thermal Conductivity/Infrared Detection Method

E1941 Test Method for Determination of Carbon in Refractory and Reactive Metals and Their Alloys

E2371 Test Method for Analysis of Titanium and Titanium Alloys by Atomic Emission Plasma Spectrometry

E2626 Guide for Spectrometric Analysis of Reactive and Refractory Metals

3. Terminology

3.1 Definitions of Terms Specific to This Standard:

3.1.1 Any product 0.187 in. (4.75 mm) and under in thickness and less than 24 in. (610 mm) in width is classified as strip; products 0.187 in. (4.75 mm) and under in thickness and 24 in. (610 mm) or more in width are classified as sheet; any product over 0.187 in. (4.75 mm) in thickness and over 10 in. (254 mm) in width is classified as plate.

4. Ordering Information

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

4.1.1 Grade number (Section 1),

4.1.2 Product limitations (Section 3),

4.1.3 Special mechanical properties (Table 1),

4.1.4 Marking (Section 16),

4.1.5 Finish (Section 8),

4.1.6 Packaging (Section 16),

4.1.7 Additional required reports (Section 15), and

4.1.8 Disposition of rejected material (Section 14).

5. Chemical Composition

5.1 The grades of titanium and titanium alloy metal covered by this specification shall conform to the chemical composition requirements prescribed in Table 2.

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

5.1.1.1 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 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.

5.1.2 Elements intentionally added to the melt must be identified, analyzed, and reported in the chemical analysis.

5.2 When agreed upon by 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.

5.3 *Product Analysis*—Product analysis tolerances do not broaden the specified heat analysis requirements but cover variations between laboratories in the measurement of chemical content. The manufacturer shall not ship material that is outside the limits specified in Table 2 for the applicable grade. Product analysis limits shall be as specified in Table 3.

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

6. Mechanical Properties

6.1 Material supplied under this specification shall conform to the mechanical property requirements given in Table 1 for the grade specified.

6.2 Tension testing specimens are to be machined and tested in accordance with Test Methods E8. Tensile properties shall be determined using a strain rate of 0.003 to 0.007 in./in./min through the specified yield strength, and then increasing the rate so as to produce failure in approximately one additional minute.

6.3 For sheet and strip, the bend test specimen shall withstand being bent cold through an angle of 105° without fracture in the outside of the bent portion. The bend shall be made on a radius equal to that shown in Table 1 for the applicable grade. The bends are to be made in accordance with Test Method E290, using Method 1, Guided Bend Test described in paragraph 3.6, bent through 105°, and allowed to spring back naturally. The surface of the specimen must include the original

³ 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.

TABLE 1 Tensile Requirements^A

Grade	Tensile Strength, min		Yield Strength, 0.2 % Offset				Elongation in 2 in. or 50 mm, min, %	Bend Test (Radius of Mandrel) ^B	
	ksi	MPa	min		max			Under 0.070 in. (1.8 mm) in Thickness	0.070 to 0.187 in. (1.8–4.75 mm) in Thickness
			ksi	MPa	ksi	MPa			
1	35	240	20	138	45	310	24	1.5T	2T
2	50	345	40	275	65	450	20	2T	2.5T
2H ^{C,D}	58	400	40	275	65	450	20	2T	2T
3	65	450	55	380	80	550	18	2T	2.5T
4	80	550	70	483	95	655	15	2.5T	3T
5	130	895	120	828	...	...	10 ^E	4.5T	5T
6	120	828	115	793	...	...	10 ^E	4T	4.5T
7	50	345	40	275	65	450	20	2T	2.5T
7H ^{C,D}	58	400	40	275	65	450	20	2T	2T
9	90	620	70	483	...	...	15 ^F	2.5T	3T
11	35	240	20	138	45	310	24	1.5T	2T
12	70	483	50	345	...	...	18	2T	2.5T
13	40	275	25	170	...	...	24	1.5T	2T
14	60	410	40	275	...	...	20	2T	2.5T
15	70	483	55	380	...	...	18	2T	2.5T
16	50	345	40	275	65	450	20	2T	2.5T
16H ^{C,D}	58	400	40	275	65	450	20	2T	2T
17	35	240	20	138	45	310	24	1.5T	2T
18	90	620	70	483	...	...	15 ^F	2.5T	3T
19 ^{G,H}	115	793	110	759	...	...	15	3T	3T
20 ^{G,H}	115	793	110	759	...	...	15	3T	3T
21 ^{G,H}	115	793	110	759	...	...	15	3T	3T
23 ^{G,H}	120	828	110	759	...	...	10	4.5T	5T
24	130	895	120	828	...	...	10	4.5T	5T
25	130	895	120	828	...	...	10	4.5T	5T
26	50	345	40	275	65	450	20	2T	2.5T
26H ^{C,D}	58	400	40	275	65	450	20	2T	4T
27	35	240	20	138	45	310	24	1.5T	2T
28	90	620	70	483	...	...	15	2.5T	3T
29	120	828	110	759	...	...	10	4.5T	5T
30	50	345	40	275	65	450	20	2T	2.5T
31	65	450	55	380	80	550	18	2T	2.5T
32	100	689	85	586	...	...	10 ^E	3.5T	4.5T
33	50	345	40	275	65	450	20	2T	2.5T
34	65	450	55	380	80	550	18	2T	2.5T
35	130	895	120	828	...	...	5	8T	8T
36	65	450	60	410	95	655	10	4.5T	5T
37	50	345	31	215	65	450	20	2T	2.5T
38	130	895	115	794	...	...	10	4T	4.5T

^A Minimum and maximum limits apply to tests taken both longitudinal and transverse to the direction of rolling. Mechanical properties for conditions other than annealed or plate thickness over 1 in. (25 mm) may be established by agreement between the manufacturer and the purchaser.

^B Bend to **Radius of Mandrel**, *T* equals the thickness of the bend test specimen. Bend tests are not applicable to material over 0.187 in. (4.75 mm) in thickness.

^C 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.

^D 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.

^E For Grades 5, 6 and 32 the elongation on materials under 0.025 in. (0.635 mm) in thickness may be obtained only by negotiation.

^F Elongation for continuous rolled and annealed (strip product from coil) for Grade 9 and Grade 18 shall be 12 % minimum in the longitudinal direction and 8 % minimum in the transverse direction.

^G Properties for material in the solution treated condition.

^H Material is normally purchased in the solution treated condition. Therefore, properties for aged material shall be negotiated between manufacturer and purchaser.

material surface with no material removal or surface conditioning, except corners may be rounded to a maximum radius of 0.032 in. (0.8 mm). The width of the bend shall be at least 5 times the thickness. The test report shall, at minimum, indicate acceptable or unacceptable results.

7. Permissible Variations in Dimensions

7.1 Dimensional tolerances on titanium and titanium alloy material covered by this specification shall be as specified in **Tables 4-13**, as applicable.

8. Finish

8.1 Titanium and titanium alloy sheet, strip, and plate shall be free of injurious external and internal imperfections of a

nature that will interfere with the purpose for which it is intended. Annealed material may be furnished as descaled, as sandblasted, or as ground, or both sandblasted and ground. If shipped as descaled, sandblasted, or ground, the manufacturer shall be permitted to remove minor surface imperfections by spot grinding if such grinding does not reduce the thickness of the material below the minimum permitted by the tolerance for the thickness ordered.

9. Sampling for Chemical Analysis

9.1 Samples for chemical analysis shall be representative of the material being tested. The utmost care must be used in sampling titanium for chemical analysis because of its great affinity for elements such as oxygen, nitrogen, and hydrogen.

TABLE 2 Chemical Requirements

Composition, Weight Percent^{A,B,C,D,E}

Grade	Carbon, max.	Oxygen range or max.	Nitrogen, max.	Hydrogen, max.	Iron range or max.	Aluminum	Vanadium	Palladium	Ruthenium	Nickel	Molybdenum	Chromium	Cobalt	Zirconium	Niobium	Tin	Silicon	Other Elements, max. each	Other Elements, max. total
1	0.08	0.18	0.03	0.015	0.20	--	--	--	--	--	--	--	--	--	--	--	--	0.1	0.4
2	0.08	0.25	0.03	0.015	0.30	--	--	--	--	--	--	--	--	--	--	--	--	0.1	0.4
2H	0.08	0.25	0.03	0.015	0.30	--	--	--	--	--	--	--	--	--	--	--	--	0.1	0.4
3	0.08	0.35	0.05	0.015	0.30	--	--	--	--	--	--	--	--	--	--	--	--	0.1	0.4
4	0.08	0.40	0.05	0.015	0.50	--	--	--	--	--	--	--	--	--	--	--	--	0.1	0.4
5	0.08	0.20	0.05	0.015	0.40	5.5-6.75	3.5-4.5	--	--	--	--	--	--	--	--	--	--	0.1	0.4
6	0.08	0.20	0.03	0.015	0.50	4.0-6.0	--	--	--	--	--	--	--	--	--	2.0-3.0	--	0.1	0.4
7	0.08	0.25	0.03	0.015	0.30	--	--	0.12-0.25	--	--	--	--	--	--	--	--	--	0.1	0.4
7H	0.08	0.25	0.03	0.015	0.30	--	--	0.12-0.25	--	--	--	--	--	--	--	--	--	0.1	0.4
9	0.08	0.15	0.03	0.015	0.25	2.5-3.5	2.0-3.0	--	--	--	--	--	--	--	--	--	--	0.1	0.4
11	0.08	0.18	0.03	0.015	0.20	--	--	0.12-0.25	--	--	--	--	--	--	--	--	--	0.1	0.4
12	0.08	0.25	0.03	0.015	0.30	--	--	--	--	0.6-0.9	0.2-0.4	--	--	--	--	--	--	0.1	0.4
13	0.08	0.10	0.03	0.015	0.20	--	--	--	0.04-0.06	0.4-0.6	--	--	--	--	--	--	--	0.1	0.4
14	0.08	0.15	0.03	0.015	0.30	--	--	--	0.04-0.06	0.4-0.6	--	--	--	--	--	--	--	0.1	0.4
15	0.08	0.25	0.05	0.015	0.30	--	--	--	0.04-0.06	0.4-0.6	--	--	--	--	--	--	--	0.1	0.4
16	0.08	0.25	0.03	0.015	0.30	--	--	0.04-0.08	--	--	--	--	--	--	--	--	--	0.1	0.4
16H	0.08	0.25	0.03	0.015	0.30	--	--	0.04-0.08	--	--	--	--	--	--	--	--	--	0.1	0.4
17	0.08	0.18	0.03	0.015	0.20	--	--	0.04-0.08	--	--	--	--	--	--	--	--	--	0.1	0.4
18	0.08	0.15	0.03	0.015	0.25	2.5-3.5	2.0-3.0	0.04-0.08	--	--	--	--	--	--	--	--	--	0.1	0.4
19	0.05	0.12	0.03	0.02	0.30	3.0-4.0	7.5-8.5	--	--	--	3.5-4.5	5.5-6.5	--	3.5-4.5	--	--	--	0.15	0.4
20	0.05	0.12	0.03	0.02	0.30	3.0-4.0	7.5-8.5	0.04-0.08	--	--	3.5-4.5	5.5-6.5	--	3.5-4.5	--	--	--	0.15	0.4
21	0.05	0.17	0.03	0.015	0.40	2.5-3.5	--	--	--	--	14.0-16.0	--	--	--	2.2-3.2	--	0.15-0.25	0.1	0.4
23	0.08	0.13	0.03	0.0125	0.25	5.5-6.5	3.5-4.5	--	--	--	--	--	--	--	--	--	--	0.1	0.4
24	0.08	0.20	0.05	0.015	0.40	5.5-6.75	3.5-4.5	0.04-0.08	--	--	--	--	--	--	--	--	--	0.1	0.4
25	0.08	0.20	0.05	0.015	0.40	5.5-6.75	3.5-4.5	0.04-0.08	--	0.3-0.8	--	--	--	--	--	--	--	0.1	0.4
26	0.08	0.25	0.03	0.015	0.30	--	--	--	0.08-0.14	--	--	--	--	--	--	--	--	0.1	0.4
26H	0.08	0.25	0.03	0.015	0.30	--	--	--	0.08-0.14	--	--	--	--	--	--	--	--	0.1	0.4
27	0.08	0.18	0.03	0.015	0.20	--	--	--	0.08-0.14	--	--	--	--	--	--	--	--	0.1	0.4
28	0.08	0.15	0.03	0.015	0.25	2.5-3.5	2.0-3.0	--	0.08-0.14	--	--	--	--	--	--	--	--	0.1	0.4
29	0.08	0.13	0.03	0.0125	0.25	5.5-6.5	3.5-4.5	--	0.08-0.14	--	--	--	--	--	--	--	--	0.1	0.4
30	0.08	0.25	0.03	0.015	0.30	--	--	0.04-0.08	--	--	--	--	0.20-0.80	--	--	--	--	0.1	0.4
31	0.08	0.35	0.05	0.015	0.30	--	--	0.04-0.08	--	--	--	--	0.20-0.80	--	--	--	--	0.1	0.4
32	0.08	0.11	0.03	0.015	0.25	4.5-5.5	0.6-1.4	--	--	--	0.6-1.2	--	--	0.6-1.4	--	0.6-1.4	0.06-0.14	0.1	0.4
33	0.08	0.25	0.03	0.015	0.30	--	--	0.01-0.02	0.02-0.04	0.35-0.55	--	0.1-0.2	--	--	--	--	--	0.1	0.4
34	0.08	0.35	0.05	0.015	0.30	--	--	0.01-0.02	0.02-0.04	0.35-0.55	--	0.1-0.2	--	--	--	--	--	0.1	0.4
35	0.08	0.25	0.05	0.015	0.20-0.80	4.0-5.0	1.1-2.1	--	--	--	1.5-2.5	--	--	--	--	--	0.20-0.40	0.1	0.4
36	0.04	0.16	0.03	0.0035	0.03	--	--	--	--	--	--	--	--	--	42.0-47.0	--	--	0.1	0.4
37	0.08	0.25	0.03	0.015	0.30	1.0-2.0	--	--	--	--	--	--	--	--	--	--	--	0.1	0.4
38	0.08	0.20-0.30	0.03	0.015	1.2-1.8	3.5-4.5	2.0-3.0	--	--	--	--	--	--	--	--	--	--	0.1	0.4

^A At minimum, the analysis of samples from the top and bottom of the ingot shall be completed and reported for all elements listed for the respective grade in this table.

^B Final product hydrogen shall be reported. Ingot hydrogen need not be reported. Lower hydrogen may be obtained by negotiation with the manufacturer.

^C Single values are maximum. The percentage of titanium is determined by difference.

^D Other elements need not be reported unless the concentration level is greater than 0.1 % each, or 0.4 % total. Other elements may not be added intentionally. Other elements may be present in titanium or titanium alloys in small quantities and are inherent to the manufacturing process. In titanium these elements typically include aluminum, vanadium, tin, chromium, molybdenum, niobium, zirconium, hafnium, bismuth, ruthenium, palladium, yttrium, copper, silicon, cobalt, tantalum, nickel, boron, manganese, and tungsten.

^E The purchaser may, in the written purchase order, request analysis for specific elements not listed in this specification.