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Standard Specification for Titanium and Titanium Alloy Forgings[1]

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1. Scope

1.1 This specification[2] covers ~~35~~39 grades of annealed titanium and titanium alloy forgings as follows:
1.1.1 *Grade F-1*—Unalloyed titanium,
1.1.2 *Grade F-2*—Unalloyed titanium,
1.1.2.1 *Grade F-2H*—Unalloyed titanium (Grade 2 with 58 ksi minimum UTS),
1.1.3 *Grade F-3*—Unalloyed titanium,
1.1.4 *Grade F-4*—Unalloyed titanium,
1.1.5 *Grade F-5*—Titanium alloy (6 % aluminum, 4 % vanadium),
1.1.6 *Grade F-6*—Titanium alloy (5 % aluminum, 2.5 % tin),
1.1.7 *Grade F-7*—Unalloyed titanium plus 0.12 to 0.25 % palladium,
1.1.7.1 *Grade F-7H*—Unalloyed titanium plus 0.12 to 0.25 % palladium (Grade 7 with 58 ksi minimum UTS),
1.1.8 *Grade F-9*—Titanium alloy (3 % aluminum, 2.5 % vanadium),
1.1.9 *Grade F-11*—Unalloyed titanium plus 0.12 to 0.25 % palladium,
1.1.10 *Grade F-12*—Titanium alloy (0.3 % molybdenum, 0.8 % nickel),
1.1.11 *Grade F-13*—Titanium alloy (0.5 % nickel, 0.05 % ruthenium),
1.1.12 *Grade F-14*—Titanium alloy (0.5 % nickel, 0.05 % ruthenium),
1.1.13 *Grade F-15*—Titanium alloy (0.5 % nickel, 0.05 % ruthenium),
1.1.14 *Grade F-16*—~~Unalloyed titanium plus 0.04% to 0.08% palladium,~~ —Unalloyed titanium plus 0.04 to 0.08 % palladium,
1.1.14.1 *Grade F-16H*—Unalloyed titanium plus 0.04 to 0.08 % palladium (Grade 16 with 58 ksi minimum UTS),
1.1.15 *Grade F-17*—Unalloyed titanium plus ~~0.04%~~0.04 to 0.08 % palladium,
1.1.16 *Grade F-18*—Titanium alloy (3 % aluminum, 2.5 % vanadium) plus 0.04 % to 0.08 % palladium,
1.1.17 *Grade F-19*—Titanium alloy (3 % aluminum, 8 % vanadium, 6 % chromium, 4 % zirconium, 4 % molybdenum),
1.1.18 *Grade F-20*—Titanium alloy (3 % aluminum, 8 % vanadium, 6 % chromium, 4 % zirconium, 4 % molybdenum) plus ~~0.04%~~0.04 to 0.08 % palladium,
1.1.19 *Grade F-21*—Titanium alloy (3 % aluminum, 2.7 % niobium, 15 % molybdenum, 0.25 % silicon),
1.1.20 *Grade F-23*—Titanium alloy (6 % aluminum, 4 % vanadium, extra low interstitials, ELI),
1.1.21 *Grade F-24*—Titanium alloy (6 % aluminum, 4 % vanadium) plus ~~0.04%~~0.04 to 0.08 % palladium,
1.1.22 *Grade F-25*—Titanium alloy (6 % aluminum, 4 % vanadium) plus ~~0.3%~~0.3 to 0.8 % nickel and ~~0.04%~~0.04 to 0.08 % palladium,
1.1.23 *Grade F-26*—Unalloyed titanium plus 0.08 to 0.14 % ruthenium,
1.1.23.1 *Grade F-26H*—Unalloyed titanium plus 0.08 to 0.14 % ruthenium (Grade 26 with 58 ksi minimum UTS),
1.1.24 *Grade F-27*—Unalloyed titanium plus 0.08 to 0.14 % ruthenium,
1.1.25 *Grade F-28*—~~Titanium alloy (3% aluminum, 2.5% vanadium plus 0.08–0.14% ruthenium),~~ —Titanium alloy (3 % aluminum, 2.5 % vanadium plus 0.08 to 0.14 % ruthenium),
1.1.26 *Grade F-29*—~~Titanium alloy (6% aluminum, 4% vanadium, extra low interstitial, ELI plus 0.08–0.14% ruthenium),~~ —Titanium alloy (6 % aluminum, 4 % vanadium, extra low interstitial, ELI plus 0.08 to 0.14 % ruthenium),
1.1.27 *Grade F-30*—Titanium alloy (0.3 % cobalt, 0.05 % palladium),
1.1.28 *Grade F-31*—Titanium alloy (0.3 % cobalt, 0.05 % palladium),
1.1.29 *Grade F-32*—Titanium alloy (5 % aluminum, 1 % vanadium, 1 % tin, 1 % zirconium, 0.8 % molybdenum),
1.1.30 *Grade F-33*—Titanium alloy (0.4 % nickel, 0.015 % palladium, 0.025 % ruthenium, 0.15 % chromium),
1.1.31 *Grade F-34*—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 Specification SB-381 in Section II of that Code.

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

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

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

1.1.35 *Grade F-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]

B 348 Specification for Titanium and Titanium Alloy Bars and Billets

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

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

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

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *bar*, *n*—a hot rolled, forged or cold worked semifinished solid section product whose cross sectional area is less than 16 in.^{2}(10 323 mm^2).

3.1.2 *billet*, *n*—a solid semifinished section, hot rolled or forged from an ingot, with a cross sectional area greater than 16 in.^{2}(10 323 mm^2).

3.1.3 *forging*, *n*—any product of work on metal formed to a desired shape by impact or pressure in hammers, forging machines, upsetters presses or related forming equipment.

4. Ordering Information

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

4.1.1 Grade number (Section 1),

4.1.2 Tensile properties (Table 1),

4.1.3 Dimensions and tolerances (Section 9),

4.1.4 Sampling, mechanical properties (Section 7),

4.1.5 Methods for chemical analysis (Section 6),

4.1.6 Marking (Section 16),

4.1.7 Packaging (Section 16),

4.1.8 Certification (Section 15),

4.1.9 Disposition of rejected material (Section 13), and

4.1.10 Supplementary requirements (S1).

[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), min or Range		Elongation in 4*D*, min, %	Reduction of Area, min, %
	ksi	(MPa)	ksi	(MPa)		
F-1	35	(240)	20	(138)	24	30
F-2	50	(345)	40	(275)	20	30
F-2H[B,C]	58	(400)	40	(275)	20	30
F-3	65†	(450)†	55	(380)	18	30
F-4	80†	(550)†	70	(483)	15	25
F-5	130	(895)	120	(828)	10	25
F-6	120	(828)	115	(795)	10	25
F-7	50	(345)	40	(275)	20	30
F-7H[B,C]	58	(400)	40	(275)	20	30
F-9	120	(828)	110	(759)	10	25
~~F-9[B]~~	~~90~~	~~(620)~~	~~70~~	~~(483)~~	~~15~~	~~25~~
F-9[D]	90	(620)	70	(483)	15	25
F-11	35	(240)	20	(138)	24	30
F-12	70	(483)	50	(345)	18	25
F-13	40	(275)	25	(170)	24	30
F-14	60	(410)	40	(275)	20	30
F-15	70	(483)	55	(380)	18	25
F-16	50	(345)	40	(275)	20	30
F-16H[B,C]	58	(400)	40	(275)	20	30
F-17	35	(240)	20	(138)	24	30
F-18	90	(620)	70	(483)	15	25
~~F-18[B]~~	~~90~~	~~(620)~~	~~70~~	~~(483)~~	~~12~~	~~20~~
F-18[D]	90	(620)	70	(483)	12	20
~~F-19[C]~~	~~115~~	~~(793)~~	~~110~~	~~(759)~~	~~15~~	~~25~~
F-19[E]	115	(793)	110	(759)	15	25
~~F-19[D]~~	~~135~~	~~(930)~~	~~130 to 159~~	~~(897) to (1096)~~	~~10~~	~~20~~
F-19[F]	135	(930)	130 to 159	(897) to (1096)	10	20
~~F-19[E]~~	~~165~~	~~(1138)~~	~~160 to 185~~	~~(1104) to (1276)~~	~~5~~	~~20~~
F-19[G]	165	(1138)	160 to 185	(1104) to (1276)	5	20
~~F-20[C]~~	~~115~~	~~(793)~~	~~110~~	~~(759)~~	~~15~~	~~25~~
F-20[E]	115	(793)	110	(759)	15	25
~~F-20[D]~~	~~135~~	~~(930)~~	~~130 to 159~~	~~(897) to (1096)~~	~~10~~	~~20~~
F-20[F]	135	(930)	130 to 159	(897) to 1096)	10	20
~~F-20[E]~~	~~165~~	~~(1138)~~	~~160 to 185~~	~~(1104) to (1276)~~	~~5~~	~~20~~
F-20[G]	165	(1138)	160 to 185	(1104) to (1276)	5	20
~~F-21[C]~~	~~115~~	~~(793)~~	~~110~~	~~(759)~~	~~15~~	~~35~~
F-21[E]	115	(793)	110	(759)	15	35
~~F-21[D]~~	~~140~~	~~(966)~~	~~130 to 159~~	~~(897) to (1096)~~	~~10~~	~~30~~
F-21[F]	140	(966)	130 to 159	(897) to 1096)	10	30
~~F-21[E]~~	~~170~~	~~(1172)~~	~~160 to 185~~	~~(1104) to (1276)~~	~~8~~	~~20~~
F-21[G]	170	(1172)	160 to 185	(1104) to (1276)	8	20
F-23	120	(828)	110	(759)	10	25
~~F-23[B]~~	~~120~~	~~(828)~~	~~110~~	~~(759)~~	~~7.5[F], 6.0[G]~~	~~25~~
F-23[D]	120	(828)	110	(759)	7.5[H], 6.0[I]	25
F-24	130	(895)	120	(828)	10	25
F-25	130	(895)	120	(828)	10	25
F-26	50	(345)	40	(275)	20	30
F-26H[B,C]	58	(400)	40	(275)	20	30
F-27	35	(240)	20	(138)	24	30
F-28	90	(620)	70	(483)	15	25
~~F-28[B]~~	~~90~~	~~(620)~~	~~70~~	~~(483)~~	~~12~~	~~20~~
F-28[D]	90	(620)	70	(483)	12	20
F-29	120	(828)	110	(759)	10	25
~~F-29[B]~~	~~120~~	~~(828)~~	~~110~~	~~(759)~~	~~7.5[F], 6.0[G]~~	~~15~~
F-29[D]	120	(828)	110	(759)	7.5[H], 6.0[I]	15
F-30	50	(345)	40	(275)	20	30
F-31	65	(450)	55	(380)	18	30
F-32	100	(689)	85	(586)	10	25
F-33	50	(345)	40	(275)	20	30
F-34	65	(450)	55	(380)	18	30
F-35	130	(895)	120	(828)	5	20
F-36	65	(450)	60 to 95	(410 to 655)	10	...
F-37	50	(345)	31	(215)	20	30
F-38	130	(895)	115	(794)	10	25

[A] These properties apply to forgings having a cross section no greater than 3 in.^{2}(1935 mm^2). Mechanical properties of forgings having greater cross sections shall be negotiated between the manufacturer and the purchaser.

[B] Properties for material in transformed-beta condition.

[C] Properties for material in the solution treated condition.

[D] Properties for solution treated and aged condition-Moderate strength (determined by aging temperature).

[E] Properties for solution treated and aged condition-High Strength (determined by aging temperature).

[F] For product section or wall thickness values <1.0 in.

[G] ~~Properties for solution treated and aged condition-High Strength (determined by aging temperature).~~

[H] For product section or wall thickness values <1.0 in.

[I] For product section or wall thickness values ≤1.0 in.

† Tensile strength for Grade F-3 and F-4 was corrected editorially.

TABLE 2 Chemical Requirements[A]

Element	Composition, %											
	F-1	F-2	F-2H	F-3	F-4	F-5	F-6	F-7	F-7H	F-9	F-11	F-12
Nitrogen, max	0.03	0.03	0.03	0.05	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	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	0.015
Iron, max	0.20	0.30	0.30	0.30	0.50	0.40	0.50	0.30	0.30	0.25	0.20	0.30
Oxygen, max	0.18	0.25	0.25	0.35	0.40	0.20	0.20	0.25	0.25	0.15	0.18	0.25
Aluminum	...	...	...	...	...	5.5–6.75	4.0–6.0	...	...	2.5–3.5	...	...
Vanadium	...	...	...	...	...	3.5–4.5	...	...	...	2.0–3.0	...	...
Tin	...	...	...	...	...	...	2.0–3.0	...	...	...	...	...
Ruthenium	...	...	...	...	...	...	...	...	...	...	...	...
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
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	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	0.4
Titanium[G]	balance	balance	balance	balance	balance	balance	balance	balance	balance	balance	balance	balance

Element	Composition, %										
	F-13	F-14	F-15	F-16	F-16H	F-17	F-18	F-19	F-20	F-21	F-23
Nitrogen, max	0.03	0.03	0.05	0.03	0.03	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	0.05	0.05	0.05	0.08
Hydrogen,[B,C] max	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.02	0.02	0.015	0.0125
Iron, max	0.20	0.30	0.30	0.30	0.30	0.20	0.25	0.30	0.30	0.40	0.25
Oxygen, max	0.10	0.15	0.25	0.25	0.25	0.18	0.15	0.12	0.12	0.17	0.13
Aluminum	...	...	...	...	...	...	2.5–3.5	3.0–4.0	3.0–4.0	2.5–3.5	5.5–6.5
Vanadium	...	...	...	...	...	...	2.0–3.0	7.5–8.5	7.5–8.5	...	3.5–4.5
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	...	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	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	0.1	0.15	0.15	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, %						
	F-24	F-25	F-26	F-26H	F-27	F-28	F-29
Nitrogen, max	0.05	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	0.08
Hydrogen,[B,C] max	0.015	0.0125	0.015	0.015	0.015	0.015	0.015
Iron, max	0.40	0.40	0.30	0.30	0.20	0.25	0.25
Oxygen, max	0.20	0.20	0.25	0.25	0.18	0.15	0.13
Aluminum	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	...	...	...	2.0–3.0	3.5–4.5
Tin	...	...	...	...	...	...	...
Ruthenium	...	...	0.08-0.14	0.8–0.14	0.08-0.14	0.08–0.14	0.08–0.14
Palladium	0.04–0.08	0.04–0.08	...	...	...	...	...
Cobalt	...	...	...	...	...	...	...
Molybdenum	...	...	...	...	...	...	...
Chromium	...	...	...	...	...	...	...
Nickel	...	0.3–0.8	...	...	...	...	...
Niobium	...	...	...	...	...	...	...
Zirconium	...	...	...	...	...	...	...
Silicon	...	...	...	...	...	...	...
Residuals,[D,E,F] max each	0.1	0.1	0.1	0.1	0.1	0.1	0.1