~~Designation:B381–05~~ Designation: B 381 – 05$^{\varepsilon 1}$

Standard Specification for Titanium and Titanium Alloy Forgings[1]

This standard is issued under the fixed designation B 381; 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 F-3 and Grade F-4 in Table 1 was corrected editorially in January 2006.

1. Scope

1.1 This specification[2] covers 34 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,
1.1.3 *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,
1.1.8 *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,
1.1.15 *Grade F-17*—Unalloyed titanium plus 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 % 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 % to 0.08 % palladium,
1.1.22 *Grade F-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 F-26*—Unalloyed titanium plus 0.08 to 0.14 % ruthenium,
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),
1.1.26 *Grade F-29*—Titanium alloy (6% aluminum, 4% vanadium, extra low interstitial, ELI plus 0.08–0.14% 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),
1.1.32 *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), and
1.1.34 *Grade F-37*—Titanium alloy (1.5 % aluminum).

1.2

[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.

Current edition approved Jan. 1, 2005. Published February 2005. Originally approved in 1961. Last previous edition approved in 2003 as B 381 – 03.

[2] For ASME Boiler and Pressure Vessel Code applications, see related Specification SB-381 in Section II of that Code.

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).

5. Materials and Manufacture

5.1 Material conforming to the latest revision of Specification B 348 shall be used when producing forgings to this specification.

6. Chemical Composition

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

6.1.1 The elements listed in Table 2 are intentional alloy additions or elements which are inherent to the manufacturer 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 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 his written purchase order, chemical analysis shall be completed for specific residual elements not listed in this specification.

6.3 *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 which is outside the limits specified in Table 2 for the applicable grade. Product analysis limits shall be as specified in Table 3.

6.4 *Sampling*—Samples for chemical analysis shall be representative of material being tested. Except for hydrogen and unless otherwise specified, chemical analysis of ingot or billet shall be reported. Samples for hydrogen determination shall be obtained from the forgings on a test basis and a frequency as agreed upon between the forger and the purchaser. 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. Therefore, the cutting and handling of samples should include practices that will prevent contamination. Samples shall be collected from clean metal.

[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-3	72.5	(500)	55	(380)	18	30
F-4	85	(860)	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-9	120	(828)	110	(759)	10	25
F-9[B]	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-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-19[C]	115	(793)	110	(759)	15	25
F-19[D]	135	(930)	130 to 159	(897) to (1096)	10	20
F-19[E]	165	(1138)	160 to 185	(1104) to (1276)	5	20
F-20[C]	115	(793)	110	(759)	15	25
F-20[D]	135	(930)	130 to 159	(897) to (1096)	10	20
F-20[E]	165	(1138)	160 to 185	(1104) to (1276)	5	20
F-21[C]	115	(793)	110	(759)	15	35
F-21[D]	140	(966)	130 to 159	(897) to (1096)	10	30
F-21[E]	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[B]	120	(828)	110	(759)	7.5[F], 6.0[G]	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-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-29	120	(828)	110	(759)	10	25
~~F-29[B]~~	~~120~~	~~(828)~~	~~110~~	~~(759)~~	~~7.5,[F] 6.0[G]~~	~~15~~
F-29[B]	120	(828)	110	(759)	7.5[F], 6.0[G]	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

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

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

6.5 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.

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

7. Mechanical Properties

7.1 Forgings supplied under this specification shall conform to the requirements as to mechanical properties specified in Table 1, as applicable.

7.2 Specimens for tension tests shall be machined and tested in accordance with Test Methods E 8. Tensile properties shall be determined using a strain rate of 0.003 to 0.007 in./in.·min through the specified yield strength. After the specified yield strength has been reached, the crosshead speed shall be increased to a rate sufficient to produce fracture in approximately one additional minute.

TABLE 2 Chemical Requirements[A]

Element	Composition, %									
	F-1	F-2	F-3	F-4	F-5	F-6	F-7	F-9	F-11	F-12
Nitrogen, max	0.03	0.03	0.05	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	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
Iron, max	0.20	0.30	0.30	0.50	0.40	0.50	0.30	0.25	0.20	0.30
Oxygen, max	0.18	0.25	0.35	0.40	0.20	0.20	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	...
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
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	balance	balance

Element	Composition, %									
	F-13	F-14	F-15	F-16	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
Carbon, max	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	0.02	0.02	0.015	0.0125
Iron, max	0.20	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	0.18	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	...	...
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	0.15	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
Titanium[G]	balance	balance	balance	balance	balance	balance	balance	balance	balance	balance

Element	Composition, %				
	F-24	F-25	F-26	F-27	F-28
Nitrogen, max	0.05	0.05	0.03	0.03	0.03
Carbon, max	0.08	0.08	0.08	0.08	0.08
Hydrogen,[B,C] max	0.015	0.0125	0.015	0.015	0.015
Iron, max	0.40	0.40	0.30	0.20	0.25
Oxygen, max	0.20	0.20	0.25	0.18	0.15
Aluminum	5.5–6.75	5.5–6.75	...	...	2.5–3.5
Vanadium	3.5–4.5	3.5–4.5	...	...	2.0–3.0
Tin	...	...			...
Ruthenium	...	...	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