Designation: B 381 – 08a

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.

1. Scope

1.1 This specification[2] covers 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,

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 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,

1.1.23.1 *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 to 0.14 % ruthenium),

1.1.26 *Grade F-29*—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),

1.1.32 *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).

[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.

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

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

E 1941 Test Method for Determination of Carbon in Refractory and Reactive Metals and Their Alloys

E 2371 Test Method for Analysis of Titanium and Titanium Alloys by Atomic Emission Plasma Spectrometry

E 2626 Guide for Spectrometric Analysis of Reactive and Refractory Metals

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 10),

4.1.4 Sampling, mechanical properties (Section 8),

4.1.5 Methods for chemical analysis (Section 6),

4.1.6 Marking (Section 17),

4.1.7 Packaging (Section 17),

4.1.8 Certification (Section 16),

4.1.9 Disposition of rejected material (Section 14), 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.

6.5 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. Methods of Chemical Analysis

7.1 The chemical analysis shall normally be conducted using the ASTM standard test methods referenced in 2.1. Other industry standard methods may be used where the ASTM test methods in 2.1 do not adequately cover the elements in the

[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[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[D]	90	(620)	70	(483)	12	20
F-19[E]	115	(793)	110	(759)	15	25
F-19[F]	135	(930)	130 to 159	(897) to (1096)	10	20
F-19[G]	165	(1138)	160 to 185	(1104) to (1276)	5	20
F-20[E]	115	(793)	110	(759)	15	25
F-20[F]	135	(930)	130 to 159	(897) to (1096)	10	20
F-20[G]	165	(1138)	160 to 185	(1104) to (1276)	5	20
F-21[E]	115	(793)	110	(759)	15	35
F-21[F]	140	(966)	130 to 159	(897) to (1096)	10	30
F-21[G]	170	(1172)	160 to 185	(1104) to (1276)	8	20
F-23	120	(828)	110	(759)	10	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[D]	90	(620)	70	(483)	12	20
F-29	120	(828)	110	(759)	10	25
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] Material is identical to the corresponding numeric grade (that is, Grade F-2H = Grade F-2) except for the higher guaranteed minimum UTS, and may be dual certified with its corresponding numeric grade. Grade F-2H, F-7H, F-16H, and F-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 transformed-beta condition.

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

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

[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

TABLE 2 *Continued*

Element	Composition, %						
	F-24	F-25	F-26	F-26H	F-27	F-28	F-29
Residuals,[D,E,F] max total	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Titanium[G]	balance	balance	balance	balance	balance	balance	balance

Element	Composition, %								
	F-30	F-31	F-32	F-33	F-34	F-35	F-36	F-37	F-38
Nitrogen, max	0.03	0.05	0.03	0.03	0.05	0.05	0.03	0.03	0.03
Carbon, max	0.08	0.08	0.08	0.08	0.08	0.08	0.04	0.08	0.08
Hydrogen,[B,C] max	0.015	0.015	0.015	0.015	0.015	0.015	0.0035	0.015	0.015
Iron, max or range	0.30	0.30	0.25	0.30	0.30	0.20–0.80	0.03	0.30	1.2–1.8
Oxygen, max or range	0.25	0.35	0.11	0.25	0.35	0.25	0.16	0.25	0.20–0.30
Aluminum	...	...	4.5-5.5	...	...	4.0–5.0	...	1.0–2.0	3.5–4.5
Vanadium	...	...	0.6-1.4	...	...	1.1–2.1	...	...	2.0–3.0
Tin	...	...	0.6-1.4	...	...	...	...	...	...
Ruthenium	...	...	...	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	...	...	...	...
Cobalt	0.20–0.80	0.20–0.80	...	...	...	...	...	...	...
Molybdenum	...	...	0.6-1.2	...	...	1.5–2.5	...	...	...
Chromium	...	...	...	0.1-0.2	0.1-0.2	...	...	...	...
Nickel	...	...	...	0.35-0.55	0.35-0.55	...	...	...	...
Niobium	...	...	...	...	...	...	42.0–47.0	...	...
Zirconium	...	...	0.6-1.4	...	...	...	...	...	...
Silicon	...	...	0.06-0.14	...	...	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
Residuals,[D,E,F] max total	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Titanium[G]	balance	balance	balance	Remainder	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.

material or by agreement between the producer and purchaser. Alternate techniques are discussed in Guide E 2626.

8. Mechanical Properties

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

8.2 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.

8.3 *Sampling*—Tension test specimens shall be machined from material as agreed upon by the manufacturer and the purchaser.

9. Nondestructive Tests

9.1 Nondestructive test requirements such as ultrasonic test, X ray, or surface inspection shall be specified by the purchaser, if required. The standard for acceptance or rejection shall be agreed upon between the forger and the purchaser.

10. Dimensions and Permissible Variations

10.1 Dimensions and tolerances of titanium and titanium alloy forgings covered by this specification shall be as shown on the applicable forging drawing or otherwise agreed upon by the manufacturer and the purchaser.

11. Workmanship, Finish and Appearance

11.1 Titanium alloy forgings shall be free of injurious external and internal imperfections of a nature that will interfere with the purpose for which they are intended. Annealed forgings may be furnished 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 forging below the minimum permitted by the tolerance for the forging at the applicable location.

12. Retests

12.1 If the results of any chemical or mechanical property test 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 double the initial number of tests. If the results of the retest conform to the

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
Cobalt	0.2 to 0.8	±0.05
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	0.6 to 1.2	±0.15
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
Niobium	>30	±0.50
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
Tin	0.6 to 3.0	±0.15
Vanadium	0.6 to 4.5	±0.15
Vanadium	7.5 to 8.5	±0.40
Zirconium	0.6 to 1.4	±0.15
Zirconium	3.5 to 4.5	±0.20
Residuals[A] (each)	0.15	+0.02

[A] 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, iron, chromium, molybdenum, niobium, zirconium, hafnium, bismuth, ruthenium, palladium, yttrium, copper, silicon, cobalt, tantalum, nickel, boron, manganese, and tungsten.

specification, then the retest values will become the test values for certification. Only original conforming test results or the 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 14.

13. Rounding-Off Procedure

13.1 For purposes of determining conformance with this specification, 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.

14. Rejection

14.1 Forgings not conforming to this specification or to authorized modifications shall be subject to rejection. Unless otherwise specified, rejected forgings 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.

15. Referee Test and Analysis

15.1 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 using the ASTM standard methods in 2.1. The referee’s testing shall be used in determining conformance of the material to this specification.

16. Certification

16.1 The manufacturer shall supply at least one copy of the report certifying that the material supplied has been manufactured, inspected, sampled, and tested in accordance with the requirements of this specification and that the results of chemical analysis, tensile, and other tests meet the requirements of the specification for the grade specified. The report shall include results of all chemical analysis, tensile tests, and all other tests required by the specification.

17. Packaging and Package Marking

17.1 *Packaging*—Unless otherwise specified, forgings purchased under this specification shall be packaged in accordance with the manufacturer’s standard practice.

17.2 *Marking*—Forgings shall be marked for identification as agreed upon by the manufacturer and the purchaser.

18. Keywords

18.1 forgings; titanium; titanium alloys

SUPPLEMENTARY REQUIREMENTS

SUPPLEMENTARY REQUIREMENTS COVERING GRADE F3 TITANIUM FORGINGS

The following supplementary requirements are primarily intended for U.S. military applications and shall apply only when specified by the purchaser in the inquiry, contract, or order.

S1. U.S. Military Requirements

S1.1 Referenced Documents section follows.

S1.2 Unless otherwise specified in the contract or purchase order, the seller is responsible for the performance of all inspection and test requirements in this specification, and the seller may use his or other suitable facilities for the performance of the inspection and testing.

S1.3 Grade F-3 composition shall be modified as follows:

Hydrogen	0.0125 max
Iron	0.20 max
Oxygen	0.26 max

S1.4 Two tensile specimens shall be taken from each lot of forgings up to and 125 pounds, and two tensile specimens shall be taken from each forging greater than 125 pounds for verification of compliance with Grade F-3 mechanical properties of Table 3. A lot shall constitute all forgings from the same heat, of the same design and size and heat treated in the same heat treat furnace load. The test specimens shall be taken from integral prolongations or extra forgings may be provided by the forger. Forgings under 3½ in. (90 mm) in cross section may use separately forged test bars provided the wall thickness and amount of working are equivalent to the forgings being supplied. Extra forgings may be provided for samples when forgings are over 3½ in. (90 mm) in cross section provided samples cannot be taken from prolongations or by trepanning. Samples shall be taken from the section of forging having the largest cross section. The longitudinal axis of the tensile specimens shall be parallel to the major direction of metal flow in the forging.

S1.5 Repair welding is not permitted.

S1.6 Each forging shall be ultrasonically inspected in accordance with MIL-STD-2154 throughout 100 % of their volume. Inspection shall be performed after heat treating when the forging is machined to the configuration for ultrasonic inspection as shown on the forging sketch or drawing. Inspection shall be performed prior to drilling holes, cutting keyways, tapers, grooves, or machining section to final contour. Forgings shall be scanned using a straight beam technique such that all major planes are covered. Disc type forgings shall be scanned using a straight beam from at least one flat face and radially from the circumference when possible. Cylindrical, ring, and hollow forgings shall be scanned from the entire external surface using the straight beam technique, and in the axial direction to the maximum extent possible. Acceptance criteria shall be to class A of MIL-STD-2154.

S1.7 All surfaces of each forging shall be liquid penetrant inspected in accordance with NAVSEA T9074-AS-GIB-010/271. Acceptance criteria shall be in accordance with NAVSEA S9074-AR-GIB-010/278 as specified in the order.

S1.8 Forgings shall be free of foreign material and contaminants such as sulfur, lead, marking paints or machining or forming lubricants. Forgings shall be cleaned prior to any heat treatment operations. Forgings shall be free of any oxygen rich layer, such as alpha case.

S1.9 The first forging of each type and design submitted for inspection shall be the first article sample. Mechanical properties for first article inspections shall be determined throughout the forging as specified in the order (which should also include specific instructions regarding arrangements for examinations, approval of test results, and disposition of the first article samples), and the number and location of the test specimens and the acceptance criteria shall be as specified or as agreed upon between the contracting activity and the manufacturer. In addition, A full cross-section shall be macroetched in accordance with ASTM E 340 and examined at 10× magnification for uniformity, soundness, grain size and grain flow. The macro etch cross section shall evidence uniformity of quality, soundness and freedom from cracks and porosity. A fully wrought structure shall be evident and variation in grain size shall be such that it will not interfere with ultrasonic examination.

The manufacturer shall maintain a record of production practices used for the first article forging. In the event of change in the production practice in the same or subsequent order, the manufacturer shall notify the contracting activity and obtain approval of the changes. The manufacturer may be required to perform specific first article tests and examinations to verify that the change will not or has not degraded forging quality.

S1.10 The material shall be electron beam and/or plasma melted or shall be multiple melted with at least one of the melting cycles under vacuum.

S2. Referenced Documents

S2.1 *ASTM Standard:*

E 340 Test Method for Macroetching Metals and Alloys

S2.2 *Military Standards:*

T9074–AS-GIB-010/271 Requirements for Nondestructive Testing Methods

S9074–AR-GIB-010/278 Requirements for Fabrication Weldingand Inspection, and Casting Inspection and Repair for Machinery, Piping, and Pressure Vessels

MIL-STD-2154 Inspection, Ultrasonic, Wrought Metals, Processing for