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Designation: ~~B381 – 13 (Reapproved 2019)~~ B381 – 21

Standard Specification for Titanium and Titanium Alloy Forgings[1]

This standard is issued under the fixed designation B381; 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*—UNS R50250. Unalloyed titanium,

1.1.2 *Grade F-2*—UNS R50400. Unalloyed titanium,

1.1.2.1 *Grade F-2H*—UNS R50400. Unalloyed titanium (Grade 2 with 58 ksi (400 MPa) minimum UTS),

1.1.3 *Grade F-3*—UNS R50550. Unalloyed titanium,

1.1.4 *Grade F-4*—UNS R50700. Unalloyed titanium,

1.1.5 *Grade F-5*—UNS R56400. Titanium alloy (6 % aluminum, 4 % vanadium),

1.1.6 *Grade F-6*—UNS R54520. Titanium alloy (5 % aluminum, 2.5 % tin),

1.1.7 *Grade F-7*—UNS R52400. Unalloyed titanium plus 0.12 to 0.25 % palladium,

1.1.7.1 *Grade F-7H*—UNS R52400. Unalloyed titanium plus 0.12 to 0.25 % palladium (Grade 7 with 58 ksi (400 MPa) minimum UTS),

1.1.8 *Grade F-9*—UNS R56320. Titanium alloy (3 % aluminum, 2.5 % vanadium),

1.1.9 *Grade F-11*—UNS R52250. Unalloyed titanium plus 0.12 to 0.25 % palladium,

1.1.10 *Grade F-12*—UNS R53400. Titanium alloy (0.3 % molybdenum, 0.8 % nickel),

1.1.11 *Grade F-13*—UNS R53413. Titanium alloy (0.5 % nickel, 0.05 % ruthenium),

1.1.12 *Grade F-14*—UNS R53414. Titanium alloy (0.5 % nickel, 0.05 % ruthenium),

1.1.13 *Grade F-15*—UNS R53415. Titanium alloy (0.5 % nickel, 0.05 % ruthenium),

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[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.

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1.1.14 *Grade F-16*—UNS R52402. Unalloyed titanium plus 0.04 to 0.08 % palladium,

1.1.14.1 *Grade F-16H*—UNS R52402. Unalloyed titanium plus 0.04 to 0.08 % palladium (Grade 16 with 58 ksi (400 MPa) minimum UTS),

1.1.15 *Grade F-17*—UNS R52252. Unalloyed titanium plus 0.04 to 0.08 % palladium,

1.1.16 *Grade F-18*—UNS R56322. Titanium alloy (3 % aluminum, 2.5 % vanadium) plus 0.04 % to 0.08 % palladium,

1.1.17 *Grade F-19*—UNS R58640. Titanium alloy (3 % aluminum, 8 % vanadium, 6 % chromium, 4 % zirconium, 4 % molybdenum),

1.1.18 *Grade F-20*—UNS R58645. 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*—UNS R58210. Titanium alloy (3 % aluminum, 2.7 % niobium, 15 % molybdenum, 0.25 % silicon),

1.1.20 *Grade F-23*—UNS R56407. Titanium alloy (6 % aluminum, 4 % vanadium, extra low interstitials, ELI),

1.1.21 *Grade F-24*—UNS R56405. Titanium alloy (6 % aluminum, 4 % vanadium) plus 0.04 to 0.08 % palladium,

1.1.22 *Grade F-25*—UNS R56403. 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*—UNS R52404. Unalloyed titanium plus 0.08 to 0.14 % ruthenium,

1.1.23.1 *Grade F-26H*—UNS R52404. Unalloyed titanium plus 0.08 to 0.14 % ruthenium (Grade 26 with 58 ksi (400 MPa) minimum UTS),

1.1.24 *Grade F-27*—UNS R52254. Unalloyed titanium plus 0.08 to 0.14 % ruthenium,

1.1.25 *Grade F-28*—UNS R56323. Titanium alloy (3 % aluminum, 2.5 % vanadium plus 0.08 to 0.14 % ruthenium),

1.1.26 *Grade F-29*—UNS R56404. Titanium alloy (6 % aluminum, 4 % vanadium, extra low interstitial, ELI plus 0.08 to 0.14 % ruthenium),

1.1.27 *Grade F-30*—UNS R53530. Titanium alloy (0.3 % cobalt, 0.05 % palladium),

1.1.28 *Grade F-31*—UNS R53532. Titanium alloy (0.3 % cobalt, 0.05 % palladium),

1.1.29 *Grade F-32*—UNS R55111. Titanium alloy (5 % aluminum, 1 % vanadium, 1 % tin, 1 % zirconium, 0.8 % molybdenum),

1.1.30 *Grade F-33*—UNS R53442. Titanium alloy (0.4 % nickel, 0.015 % palladium, 0.025 % ruthenium, 0.15 % chromium),

1.1.31 *Grade F-34*—UNS R53445. Titanium alloy (0.4 % nickel, 0.015 % palladium, 0.025 % ruthenium, 0.15 % chromium),

1.1.32 *Grade F-35*—UNS R56340. Titanium alloy (4.5 % aluminum, 2 % molybdenum, 1.6 % vanadium, 0.5 % iron, 0.3 % silicon),

1.1.33 *Grade F-36*—UNS R58450. Titanium alloy (45 % niobium),

1.1.34 *Grade F-37*—UNS R52815. Titanium alloy (1.5 % aluminum), and

1.1.35 *Grade F-38*—UNS R54250. 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.

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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.

1.3 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

B348 Specification for Titanium and Titanium Alloy Bars and Billets
E8 Test Methods for Tension Testing of Metallic Materials [Metric] E0008_E0008M
E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
E539 Test Method for Analysis of Titanium Alloys by Wavelength Dispersive X-Ray Fluorescence Spectrometry
E1409 Test Method for Determination of Oxygen and Nitrogen in Titanium and Titanium Alloys by Inert Gas Fusion
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 by Combustion Analysis
E2371 Test Method for Analysis of Titanium and Titanium Alloys by Direct Current Plasma and Inductively Coupled Plasma Atomic Emission Spectrometry (Performance-Based Test Methodology)
E2626 Guide for Spectrometric Analysis of Reactive and Refractory Metals (Withdrawn 2017)[4]
E2994 Test Method for Analysis of Titanium and Titanium Alloys by Spark Atomic Emission Spectrometry and Glow Discharge Atomic Emission Spectrometry (Performance-Based Method)

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

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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.~~16 in.^{2} (10 323 mm^2).

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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~~if ~~6),~~different from those listed in 2.0,

4.1.6 Marking (Section 17),

4.1.7 Packaging (Section 17),

[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.
[4] The last approved version of this historical standard is referenced on www.astm.org.

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-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.

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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 B348 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.

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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.~~For chemical composition, at a minimum the analysis of samples corresponding to positions representing the top and bottom of the ingot shall be completed and reported.

NOTE 2—If chemical composition sampling is not done until the ingot is converted into billets, bars, or forgings etc., samples from opposite ends of these products corresponding to the top and bottom of the ingot may be used.

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 material or by agreement between the producer and purchaser. Alternate techniques are discussed in Guide E2626.

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.

TABLE 2 Chemical Requirements

Composition, Weight Percent[A,B,C,D,E]

Grade	UNS Number	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
F-1	R50250	0.08	0.18	0.03	0.015	0.20	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	0.1	0.4
F-2/ F-2H	R50400	0.08	0.25	0.03	0.015	0.30	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	0.1	0.4
F-3	R50550	0.08	0.35	0.05	0.015	0.30	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	0.1	0.4
F-4	R50700	0.08	0.40	0.05	0.015	0.50	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	0.1	0.4
F-5	R56400	0.08	0.20	0.05	0.015	0.40	5.5-6.75	3.5-4.5	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	0.1	0.4
F-6	R54520	0.08	0.20	0.03	0.015	0.50	4.0-6.0	- -	- -	- -	- -	- -	- -	- -	- -	- -	2.0-3.0	- -	0.1	0.4
F-7/ F-7H	R52400	0.08	0.25	0.03	0.015	0.30	- -	- -	0.12-0.25	- -	- -	- -	- -	- -	- -	- -	- -	- -	0.1	0.4
F-9	R56320	0.08	0.15	0.03	0.015	0.25	2.5-3.5	2.0-3.0	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	0.1	0.4
F-11	R52250	0.08	0.18	0.03	0.015	0.20	- -	- -	0.12-0.25	- -	- -	- -	- -	- -	- -	- -	- -	- -	0.1	0.4
F-12	R53400	0.08	0.25	0.03	0.015	0.30	- -	- -	- -	- -	0.6-0.9	0.2-0.4	- -	- -	- -	- -	- -	- -	0.1	0.4
F-13	R53413	0.08	0.10	0.03	0.015	0.20	- -	- -	- -	0.04-0.06	0.4-0.6	- -	- -	- -	- -	- -	- -	- -	0.1	0.4
F-14	R53414	0.08	0.15	0.03	0.015	0.30	- -	- -	- -	0.04-0.06	0.4-0.6	- -	- -	- -	- -	- -	- -	- -	0.1	0.4
F-15	R53415	0.08	0.25	0.05	0.015	0.30	- -	- -	- -	0.04-0.06	0.4-0.6	- -	- -	- -	- -	- -	- -	- -	0.1	0.4
F-16/ F-16H	R52402	0.08	0.25	0.03	0.015	0.30	- -	- -	0.04-0.08	- -	- -	- -	- -	- -	- -	- -	- -	- -	0.1	0.4
F-17	R52252	0.08	0.18	0.03	0.015	0.20	- -	- -	0.04-0.08	- -	- -	- -	- -	- -	- -	- -	- -	- -	0.1	0.4
F-18	R56322	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
F-19	R58640	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
F-20	R58645	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
F-21	R58210	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
F-23	R56407	0.08	0.13	0.03	0.0125	0.25	5.5-6.5	3.5-4.5	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	0.1	0.4
F-24	R56405	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
F-25	R56403	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
F-26/ F-16H	R52404	0.08	0.25	0.03	0.015	0.30	- -	- -	- -	0.08-0.14	- -	- -	- -	- -	- -	- -	- -	- -	0.1	0.4
F-27	R52254	0.08	0.18	0.03	0.015	0.20	- -	- -	- -	0.08-0.14	- -	- -	- -	- -	- -	- -	- -	- -	0.1	0.4
F-28	R56323	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
F-29	R56404	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
F-30	R53530	0.08	0.25	0.03	0.015	0.30	- -	- -	0.04-0.08	- -	- -	- -	- -	0.20-0.80	- -	- -	- -	- -	0.1	0.4

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TABLE 2 *Continued*

Grade	UNS Number	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,~~ Elem-<u>ents,</u> max. each	Other ~~Elements,~~ Elem-<u>ents,</u> max. total
		Composition, Weight Percent[A,B,C,<u>D,E</u>]																		
F-31	R53532	0.08	0.35	0.05	0.015	0.30	- -	- -	0.04-0.08	- -	- -	- -	- -	0.20-0.80	- -	- -	- -	- -	0.1	0.4
F-32	R55111	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
F-33	R53442	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
F-34	R53445	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
F-35	R56340	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
F-36	R58450	0.04	0.16	0.03	0.015	0.03	- -	- -	- -	- -	- -	- -	- -	- -	- -	42.0-47.0	- -	- -	0.1	0.4
F-37	R52815	0.08	0.25	0.03	0.015	0.30	1.0-2.0	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	0.1	0.4
F-38	R54250	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.~~

[A] 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.~~

[B] 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.

[C] The purchaser may, in the written purchase order, request analysis for specific residual elements not listed in this specification.