ASTM B381-08a

Standard Specification for Titanium and Titanium Alloy Forging[1]

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% aluminium, 4% vanadium),

1.1.6 Grade F-6 – Titanium alloy (5% aluminium, 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% aluminium, 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 % aluminium, 2.5 % vanadium) plus 0.04 % to 0.08 % palladium,

1.1.17 Grade F-19 – titanium alloy (3 % aluminium, 8 % vanadium,6 % chromium, 4 % zirconium, 4 % molybdenum),

1.1.18. Grade F-20 – titanium alloy (3 % aluminium, 8 % vanadium, 6 % chromium, 4 % zirconium, 4 % molybdenum) plus 0.04 to 0.08 % palladium,

1.1.19 Grade F-21 – titanium alloy (3 % aluminium, 2.7 % niobium, 15 % molybdenum, 0.25 % silicon),

1.1.20. Grade F-23 – titanium alloy (6 5 aluminium, 4 % vanadium, extra low interstitials, ELI),

1.1.21. Grade F-24 – titanium alloy (6 % aluminium, 4 % vanadium) plus 0.04 to 0.08 % palladium,

1.1.22. Grade F-25 – titanium alloy (6 % aluminium, 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 % aluminium, 2.5 % vanadium plus 0.08 to 0.14 % ruthenium),

1.1.26. Grade F-29 – titanium alloy (6 % aluminium, 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 % aluminium, 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 % aluminium, 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 % aluminium), and

1.1.35. Grade F-38 – titanium alloy (4 % aluminium, 2.5 % vanadium, 1.5 % iron).

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. Reference Documents :-

2.1 ASTM Standards :-

B 348 Specification for 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 specification.

F 539 test method for X-Ray fluorescence spectrometric analysis of 6AI-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 mm²).
     - 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 mm²).
     - 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 (SI).

5. Materials and Manufacture :-
   5.1 Material conforming to the latest revision of specification B 348 shall be used when producing forging to this specification.
6. Chemical Composition :-
   6.1 The grade 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 addition 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 variation 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 attest 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 including 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 tests methods referenced in 2.1. Other industry standard methods may be used where the ASTM 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 E 2626.

ASTM B381-08a

TABLE 1 Tensile Requirements[A]

Grade	Tensile Strength, min		Yield Strength (0.2% Offset),min or Range		Elongation in 4D, 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[bg]	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[bg]	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-16 H[bg]	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[3]	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[3]	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[3]	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'	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-26 H[bg]	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'	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

TABLE 2 Chemical Requirements[A]

Composition, %												
Element	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	0.03	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	0.08	0.08	0.08	0.08	0.08
Hydrogen,[bg] 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
Aluminium		....	....	....	....	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,[DEF] 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,[DEF] 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	F-24
Nitrogen, max	0.03	0.03	0.03	0.03	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	0.08	0.08	0.08	0.08	0.08
Hydrogen,[BG] 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	0.30	0.20	0.25	0.30	0.30	0.40	0.25	0.40
Oxygen, max	0.10	0.15	0.25	0.25	0.25	0.18	0.15	0.12	0.12	0.17	0.13	0.20
Aluminium	....	....	....	....	....	....	2.5-3.5	3.0-4.0	3.0-4.0	2.5-3.5	5.5-6.5	5.5-6.75
Vanadium	....	....	....	....	....	....	2.0-3.0	7.5-8.5	7.5-8.5	....	3.5-4.5	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	....	....	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	0.4-0.6	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,[DEF] max each	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.15	0.15	0.1	0.1	0.1
Residuals,[DEF] 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-25	F-26	F-26H	F-27	F-28	F-29	F-30	F-31	F-32	F-33	F-34	F-35
Nitrogen, max	0.03	0.03	0.03	0.03	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	0.08	0.08	0.08	0.08	0.08
Hydrogen,[BG] 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	0.40	0.30	0.30	0.20	0.25	0.25	0.30	0.30	0.25	0.30	0.30	0.20-0.80
Oxygen, max	0.20	0.25	0.25	0.18	0.15	0.13	0.25	0.35	0.11	0.25	0.35	0.25
Aluminium	5.5-6.75	....	....	....	2.5-3.5	5.5-6.5	....	....	4.5-5.5	....	....	4.0-5.0
Vanadium	3.5-4.5	....	....	....	2.0-3.0	3.5-4.5	....	....	0.6-1.4	.....	....	1.1-2.1
Tin	.....	.....	.....	.....	.....	.....	....	.....	0.6-1.4	.....	.....	.....
Rutheni	.....	0.08-	0.8-	0.08	0.08-	0.08	.....	.....	.....	0.02-	0.02-	.....

um		0.14	0.14	- 0.14	0.14	- 0.14.				0.04	0.04	
Palladium	0.04-0.08	.....	.....	.....	.....	.....	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	0.3-0.8	.....	.....	.....	.....	.....	.....	.....	.....	0.35-0.55	0.35-0.55	.....
Niobium	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Zirconium	.....	.....	.....	.....	.....	.....	.....	.....	0.6-1.4	.....	.....	.....
Silicon	.....	.....	.....	.....	.....	.....	.....	.....	0.06 - 0.14	.....	.....	0.20-0.40
Residuals,[DEF] 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,[DEF] 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	remainder	remainder	remainder

Element	Composition, %		
	F-36	F-37	F-38
Nitrogen, max	0.03	0.03	0.03
Carbon, max	0.04	0.08	0.08
Hydrogen,[BG] max	0.0035	0.015	0.015
Iron max	0.03	0.30	1.2-1.8
Oxygen, max	0.16	0.25	0.20-0.30
Aluminium	....	1.0-2.0	3.5-4.5
Vanadium	...	....	2.0-3.0
Tin	...	....	...

Ruthenium	....	....	...
Palladium	....	...	...
Cobalt	....	...	...
Molybdenum	....	...	...
Chromium	....	...	...
Nickel	....	...	....
Niobium	42.0-47.0	....	...
Zirconium	....	....	..
Silicon	....	...	...
Residuals,[D E] max each	0.1	0.1	0.1
Residuals,[D E] max total	0.4	0.4	0.4
Titanium[G]	Remainder	remainder	remainder

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 method E8. 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. Non-destructive Tests :-
   9.1 Non-destructive 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
12. Retests
13. Rounding Off Procedure

14. Rejection
15. Referee test and analysis
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
18. Keywords :-

18.1 forgings; titanium; titanium alloys

Supplementary Requirements :-

S1. U.S. Military Requirements
S2. Referenced Documents