Designation: B 348 – 05

Standard Specification for Titanium and Titanium Alloy Bars and Billets[1]

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This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This specification[2] covers annealed titanium and titanium alloy bars and billets as follows:

1.1.1 *Grade 1*—Unalloyed titanium,

1.1.2 *Grade 2*—Unalloyed titanium,

1.1.3 *Grade 3*—Unalloyed titanium,

1.1.4 *Grade 4*—Unalloyed titanium,

1.1.5 *Grade 5*—Titanium alloy (6 % aluminum, 4 % vanadium),

1.1.6 *Grade 6*—Titanium alloy (5 % aluminum, 2.5 % tin),

1.1.7 *Grade 7*—Unalloyed titanium plus 0.12 to 0.25 % palladium,

1.1.8 *Grade 9*—Titanium alloy (3 % aluminum, 2.5 % vanadium),

1.1.9 *Grade 11*—Unalloyed titanium plus 0.12 to 0.25 % palladium,

1.1.10 *Grade 12*—Titanium alloy (0.3 % molybdenum, 0.8 % nickel),

1.1.11 *Grade 13*—Titanium alloy (0.5 % nickel, 0.05 % ruthenium),

1.1.12 *Grade 14*—Titanium alloy (0.5 % nickel, 0.05 % ruthenium),

1.1.13 *Grade 15*—Titanium alloy (0.5 % nickel, 0.05 % ruthenium),

1.1.14 *Grade 16*—Unalloyed titanium plus 0.04 to 0.08 % palladium,

1.1.15 *Grade 17*—Unalloyed titanium plus 0.04 to 0.08 % palladium,

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

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

1.1.18 *Grade 20*—Titanium alloy (3 % aluminum, 8 % vanadium, 6 % chromium, 4 % zirconium, 4 % molybdenum) plus 0.04 %–0.08 % palladium,

1.1.19 *Grade 21*—Titanium alloy (15 % molybdenum, 3 % aluminum, 2.7 % niobium, 0.25 % silicon),

1.1.20 *Grade 23*—Titanium alloy (6 % aluminum, 4 % vanadium with extra low interstitial elements, ELI),

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

1.1.22 *Grade 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 26*—Unalloyed titanium plus 0.08 to 0.14 % ruthenium,

1.1.24 *Grade 27*—Unalloyed titanium plus 0.08 to 0.14 % ruthenium,

1.1.25 *Grade 28*—Titanium alloy (3 % aluminum, 2.5 % vanadium plus 0.08–0.14 % ruthenium),

1.1.26 *Grade 29*—Titanium alloy (6 % aluminum, 4 % vanadium, extra low interstitial, ELI plus 0.08–0.14 % ruthenium),

1.1.27 *Grade 30*—Titanium alloy (0.3 % cobalt, 0.05 % palladium),

1.1.28 *Grade 31*—Titanium alloy (0.3 % cobalt, 0.05 % palladium),

1.1.29 *Grade 32*—Titanium alloy (5 % aluminum, 1 % tin, 1 % zirconium, 1 % vanadium, 0.8 % molybdenum),

1.1.30 *Grade 33*—Titanium alloy (0.4 % nickel, 0.015 % palladium, 0.025 % ruthenium, 0.15 % chromium),

1.1.31 *Grade 34*—Titanium alloy (0.4 % nickel, 0.015 % palladium, 0.025 % ruthenium, 0.15 % chromium),

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

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

1.1.34 *Grade 37*—Titanium Alloy (1.5 % aluminum).

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] 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-348 in Section II of that Code.

2. Referenced Documents

2.1 *ASTM Standards:* [3]

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[4]

E 1409 Test Method for Determination of Oxygen 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 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 equal to or less than 16 in.^{2}(10 323 mm^2); rectangular bar must be less than or equal to 10 in. (254 mm) in width and greater than 0.1875 in. (4.8 mm) in thickness.

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) whose width is less than five times its thickness.

4. Ordering Information

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

4.1.1 Grade number (Section 1),

4.1.2 Product classification (Section 3),

4.1.3 Chemistry (Table 1),

4.1.4 Mechanical properties (Table 3),

4.1.5 Marking (Section 16),

4.1.6 Finish (Section 8),

4.1.7 Packaging (Section 16),

4.1.8 Required reports (Section 15), and

4.1.9 Disposition of rejected material (Section 14).

5. Chemical Composition

5.1 The grades of titanium and titanium alloy metal covered by this specification shall conform to the requirements as to chemical composition prescribed in Table 1.

5.1.1 The elements listed in Table 1 are intentional alloy additions or elements which are inherent to the manufacture of titanium sponge, ingot or mill product.

5.1.1.1 Elements other than those listed in Table 1 are deemed to be capable of occurring in the grades listed in Table 1 by and only by way of unregulated or unanalyzed scrap additions to the ingot melt. Therefore, product analysis for elements not listed in Table 1 shall not be required unless specified and shall be considered to be in excess of the intent of this specification.

5.1.2 Elements intentionally added to the melt must be identified, analyzed and reported in the chemical analysis.

5.2 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.

5.3 *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 1 for the applicable grade. Product analysis limits shall be as specified in Table 2.

6. Mechanical Properties

6.1 Material supplied under this specification shall conform to the mechanical property requirements given in Table 3, as applicable.

6.2 Tension testing specimens are to 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, and then increasing the rate so as to produce failure in approximately one additional minute.

7. Dimensions, Weight, and Permissible Variations

7.1 *Size*—Tolerances on titanium and titanium alloy material covered by this specification shall be as specified in Tables 4-11, as applicable.

7.2 *Weight*—Quantity extras are applicable to individual items of a grade, thickness, width, and length ordered at one time for shipment at one time to one destination. Different lengths of the same size and grade may be combined for quantity extra. The shipping weight of any item of an ordered size in any finish may exceed the theoretical weight by as much as 10 %.

8. Workmanship, Finish, and Appearance

8.1 Titanium and titanium alloy bar and billet shall be free of injurious external and internal imperfections of a nature that will interfere with the purpose for which it is intended. Annealed material may be furnished as descaled, sandblasted, ground, or rough turned. The manufacturer shall be permitted to remove minor surface imperfections by spot grinding if such grinding does not reduce the thickness of the material below the minimum permitted by the tolerance for the thickness ordered.

9. Sampling

9.1 Samples for chemical analyses shall be representative of the material being tested. 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, in cutting samples for analysis, the operation should be carried out insofar as possible in a dust-free atmosphere. Chips should be collected from clean metal and tools should be clean and sharp. Samples for analysis should be stored in suitable containers.

9.2 At least two samples for chemical analysis shall be tested to determine chemical composition. Samples shall be

[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] Withdrawn.

TABLE 1 Chemical Requirements[A]

Element	Composition, %									
	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Grade 6	Grade 7	Grade 9	Grade 11	Grade 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, %									
	Grade 13	Grade 14	Grade 15	Grade 16	Grade 17	Grade 18	Grade 19	Grade 20	Grade 21	Grade 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, %						
	Grade 24	Grade 25	Grade 26	Grade 27	Grade 28	Grade 29	Grade 30
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	0.20	0.25	0.25	0.30
Oxygen, max	0.20	0.20	0.25	0.18	0.15	0.13	0.25
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	0.08–0.14	0.08–0.14	0.08–0.14	...
Palladium	0.04–0.08	0.04–0.08	...	...	...	...	0.04–0.08
Cobalt	...	...			...	...	0.20–0.80
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 1 *Continued*

Element	Composition, %						
	Grade 24	Grade 25	Grade 26	Grade 27	Grade 28	Grade 29	Grade 30
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, %						
	Grade 31	Grade 32	Grade 33	Grade 34	Grade 35	Grade 36	Grade 37
Nitrogen, max	0.05	0.03	0.03	0.05	0.05	0.03	0.03
Carbon, max	0.08	0.08	0.08	0.08	0.08	0.04	0.08
Hydrogen,[B,C] max	0.015	0.015	0.015	0.015	0.015	0.0035	0.015
Iron, max or range	0.30	0.25	0.30	0.30	0.20–0.80	0.03	0.30
Oxygen, max	0.35	0.11	0.25	0.35	0.25	0.16	0.25
Aluminum	...	4.5–5.5	...	...	4.0-5.0	...	1.0–2.0
Vanadium	...	0.6–1.4	...	...	1.1–2.1	...	...
Tin	...	0.6–1.4	...	...	...	...	...
Ruthenium	...	...	0.02-0.04	0.02-0.04	...	...	...
Palladium	0.04–0.08	...	0.01-0.02	0.01-0.02	...	...	...
Cobalt	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
Residuals,[D,E,F] max total	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Titanium[G]	balance	balance	Remainder	Remainder	Remainder	Remainder	Remainder

[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.

taken from the ingot or from the opposite extremes of the product to be analyzed.

10. Methods of Chemical Analysis

10.1 The chemical analysis shall be conducted by the standard techniques normally utilized by the manufacturer and the purchaser. In case of disagreement Test Methods E 120 shall be used as the referee method except for carbon, oxygen, and hydrogen which are not covered in Test Methods E 120. Test Method E 1409 shall be used as a referee method for oxygen and Test E 1447 shall be used as a referee method for hydrogen.

11. Retests

11.1 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 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.

12. Referee Test and Analysis

12.1 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. The referee's testing shall be used in determining conformance of the material to this specification.

13. Rounding-Off Procedure

13.1 For purposes of determining conformance with the specifications contained herein, 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 Material not conforming to this specification or to authorized modifications shall be subject to rejection. Unless otherwise specified, rejected material 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.

TABLE 2 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
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	0.62.0 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
Residuals[A] (each)	0.15	+ 0.02

[A] A residual is an element present in a metal or 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.

15. Certification

15.1 If so requested by the purchaser, the manufacturer shall supply at least one copy of his report certifying that the material supplied has been inspected and tested in accordance with the requirements of this specification and that the results of chemical analysis and mechanical tests meet the requirements of this specification for the appropriate grade.

16. Packaging and Package Marking

16.1 *Marking*—Unless otherwise specified, individual pieces or bundles shall have attached a metal tag stamped with the purchase order number, the specification number, the nominal size and manufacturer's heat number, or shall be boxed and the box marked with the same information. In addition to the above identification, bars 1 in. (25.4 mm) and over in diameter or distance between parallel sides shall be stamped with the heat number within 2 in. (50.8 mm) of one end.

16.2 *Packaging*—Unless otherwise specified, material purchased under this specification may be packaged for shipment either by boxing, crating, single boarding, burlapping, or with no protection in accordance with the manufacturer's standard practice.

17. Keywords

17.1 bar; billet; titanium; titanium alloy

TABLE 3 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		
1	35	240	25	170	24	30
2	50	345	40	275	20	30
3	72.5	500	55	380	18	30
4	85	586	70	483	15	25
5	130	895	120	828	10	25
6	120	828	115	795	10	25
7	50	345	40	275	20	30
9	90	620	70	483	15	25
9[B]	90	620	70	483	12	25
11	35	240	25	170	24	30
12	70	483	50	345	18	25
13	40	275	25	170	24	30
14	60	410	40	275	20	30
15	70	483	55	380	18	25
16	50	345	40	275	20	30
17	35	240	25	170	24	30
18	90	620	70	483	15	25
18[B]	90	620	70	483	12	20
19[C]	115	793	110	759	15	25
19[D]	135	930	130 to 159	897 to 1096	10	20
19[E]	165	1138	160 to 185	1104 to 1276	5	20
20[C]	115	793	110	759	15	25
20[D]	135	930	130 to 159	897 to 1096	10	20
20[E]	165	1138	160 to 185	1104 to 1276	5	20
21[C]	115	793	110	759	15	35
21[D]	140	966	130 to 159	897 to 1096	10	30
21[E]	170	1172	160 to 185	1104 to 1276	8	20
23	120	828	110	759	10	15
23[B]	120	828	110	759	7.5[F], 6.0[G]	25
24	130	895	120	828	10	25
25	130	895	120	828	10	25
26	50	345	40	275	20	30
27	35	240	25	170	24	30
28	90	620	70	483	15	25
28[B]	90	620	70	483	12	20
29	120	828	110	759	10	25
29[B]	120	828	110	759	7.5[F], 6.0[G]	15
30	50	345	40	275	20	30
31	65	450	55	380	18	30
32	100	689	85	586	10	25
33	50	345	40	275	20	30
34	65	450	55	380	18	30
35	130	895	120	828	5	20
36	65	450	60 to 95	410 to 655	10	...
37	50	345	31	215	20	30

[A]These properties apply to longitudinal sections up to 3 in. (76 mm) in thickness with a maximum of 10 in.^{2}(64.5 cm^2). Mechanical properties of larger sections shall be negotiated between the manufacturer and purchaser.

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

[C]Properties for 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.

TABLE 4 Permissible Variations in Size for Titanium Bars—Hot-Rolled Rounds and Squares

Specified Size, in. (mm)	Size Variations, in. (mm)	Out-of-Round[A] or Out-of-Square,[B] in. (mm)
¼ to 5⁄16 (6.35 to 7.94), incl	±0.005 (0.13)	0.008 (0.20)
Over 5⁄16 to 7⁄16 (7.94 to 11.11), incl	±0.006 (0.15)	0.009 (0.23)
Over 7⁄16 to ⅝ (11.11 to 15.88), incl	±0.007 (0.18)	0.010 (0.25)
Over ⅝ to ⅞ (15.88 to 22.22), incl	±0.008 (0.20)	0.012 (0.30)
Over ⅞ to 1 (22.22 to 25.40), incl	±0.009 (0.23)	0.013 (0.33)
Over 1 to 1⅛ (25.40 to 28.58), incl	±0.010 (0.25)	0.015 (0.38)
Over 1⅛ to 1¼ (28.58 to 31.75), incl	±0.011 (0.28)	0.016 (0.41)
Over 1¼ to 1⅜ (31.75 to 34.92), incl	±0.012 (0.30)	0.018 (0.46)
Over 1⅜ to 1½ (34.92 to 38.10), incl	±0.014 (0.36)	0.021 (0.53)
Over 1½ to 2 (38.10 to 50.80), incl	±1⁄64 (0.40)	0.023 (0.58)
Over 2 to 2½ (50.80 to 63.50), incl	+ 1⁄32 , – 0 (0.79)	0.023 (0.58)
Over 2½ to 3½ (63.50 to 88.90), incl	+ 3⁄64 , – 0 (1.19)	0.035 (0.89)
Over 3½ to 4½ (88.90 to 114.30), incl	+ 1⁄16 , – 0 (1.59)	0.046 (1.17)

[A]Out-of-round is the difference between the maximum and minimum diameters of the bar, measured at the same cross section.
[B]Out-of-square section is the difference in the two dimensions at the same cross section of a square bar, each dimension being the distance between opposite faces.

TABLE 5 Permissible Variations in Size for Titanium Bars—Hot-Rolled Hexagons and Octagons

Specified Sizes Between Opposite Sides, in. (mm)	Size Variation, in. (mm)	Maximum Difference, 3 Measurements, in. (mm)
¼ to ½ (6.35 to 12.70), incl	±0.007 (0.18)	0.011 (0.28)
Over ½ to 1 (12.70 to 25.40), incl	±0.010 (0.25)	0.015 (0.38)
Over 1 to 1½ (25.40 to 38.10), incl	±0.021 (0.53)	0.025 (0.64)
Over 1½ to 2 (38.10 to 50.80), incl	±1⁄32 (0.79)	1⁄32 (0.79)
Over 2 to 2½ (50.80 to 63.50), incl	±3⁄64 (1.19)	3⁄64 (1.19)
Over 2½ to 3½ (63.50 to 88.90), incl	±1⁄16 (1.59)	1⁄16 (1.59)

TABLE 6 Permissible Variations in Size for Titanium Bars—Hot-Rolled Flats

Specified Widths, in. (mm)	Thickness Variation from Specified Thickness, in. (mm)			
	⅛ to ½ in. (3.18 to 12.70 mm), incl	Over ½ to 1 in. (12.70 to 25.40 mm), incl	Over 1 to 2 in. (25.40 to 50.80 mm), incl	Width Variation, in. (mm)
To 1 (25.40), incl	±0.008 (0.20)	±0.010 (0.25)	...	+ 1⁄64 , – 1⁄64 (+ 0.40, – 0.40)
Over 1 to 2 (25.40 to 50.80), incl	±0.012 (0.30)	±0.015 (0.38)	±1⁄32 (0.79)	+ 1⁄32 , – 1⁄32 (+ 0.79, – 0.79)
Over 2 to 4 (50.80 to 101.60), incl	±0.015 (0.38)	±0.020 (0.51)	±1⁄32 (0.79)	+ 1⁄16 , – 1⁄32 (+ 1.59, – 0.79)
Over 4 to 6 (101.60 to 152.40), incl	±0.015 (0.38)	±0.020 (0.51)	±1⁄32 (0.79)	+ 3⁄32 , – 1⁄16 (+ 2.38, – 1.59)
Over 6 to 8 (152.40 to 203.20), incl	±0.016 (0.41)	±0.025 (0.64)	±1⁄32 (0.79)	+ ⅛ , – 5⁄32 (+ 3.18, – 3.97)
Over 8 to 10 (203.20 to 254.0), incl	±0.021 (0.53)	±0.031 (0.79)	±1⁄32 (0.79)	+ 5⁄32 , – 3⁄16 (+ 3.97,–4.76)

TABLE 7 Permissible Variations in Size for Titanium Bars—Cold-Finished Rounds

Specified Size, in. (mm)	Size Variation,[A] in. (mm)
Over ½ to 1 (12.70 to 25.40), excl	±0.002 (0.05)
1 to 1½ (25.40 to 38.10), excl	±0.0025 (0.06)
1½ to 4 (38.10 to 101.60), incl	±0.003 (0.08)

[A] When it is necessary to heat treat or heat treat and pickle after cold finishing, because of special hardness or mechanical property requirements, tolerances are commonly double those shown in this table.

TABLE 8 Permissible Variations in Size for Titanium Bars—Cold-Finished Hexagons, Octagons, and Squares

Specified Size, in. (mm)	Size Variation,[A] in. (mm)
Over ½ to 1 (12.70 to 25.40), incl	+ 0, – 0.004 (–0.10)
Over 1 to 2 (25.40 to 50.80), incl	+ 0, – 0.006 (–0.16)
Over 2 to 3 (50.80 to 76.20), incl	+ 0, – 0.008 (–0.20)
Over 3 (76.20)	+ 0, – 0.010 (–0.25)

TABLE 9 Permissible Variations in Size for Titanium Bars—Cold-Finished Flats

Size Width or Thickness, in. (mm)	Width Variations[A] from Specified Thicknesses, in. (mm)		Thickness Variation,[A] in. (mm)
	¼ in. (6.35 mm) and under	Over ¼ in. (6.35 mm)	
Over ⅜ to 1 (9.54 to 25.40), incl	±0.004 (0.10)	±0.002 (0.05)	±0.002 (0.05)
Over 1 to 2 (25.40 to 50.80), incl	±0.006 (0.15)	±0.003 (0.08)	±0.003 (0.08)
Over 2 to 3 (50.80 to 76.20), incl	±0.008 (0.20)	±0.004 (0.10)	±0.004 (0.10)
Over 3 to 4½ (76.20 to 114.30), incl	±0.010 (0.25)	±0.005 (0.13)	±0.005 (0.13)

[A]When it is necessary to heat treat or heat treat and pickle after cold finishing, because of special hardness or mechanical property requirements, tolerances are commonly double those shown in this table.

TABLE 10 Permissible Variations in Length for Titanium Bars—Hot Rolled and Cold Finished

Specified Sizes, all Shapes, in. (mm)	Length Variations, in. (mm)	
	To 12 ft (3.66 m), incl	Over 12 to 25 ft (3.66 to 7.62 m), incl
To 2 (50.80), incl	+ ½ , – 0 (+ 12.70)	+ ¾ , – 0 (+ 19.05)
Over 2 to 4 (50.80 to 101.60), incl	+ ¾ , – 0 (+ 19.05)	+ 1, – 0 (+ 25.40)
Over 4 to 6 (101.60 to 152.40), incl	+ 1, – 0 (+ 25.40)	+ 1¼ , – 0 (+ 31.75)
Over 6 to 9 (152.40 to 228.60), incl	+ 1¼ , – 0 (+ 31.75)	+ 1½ , – 0 (+ 38.10)
Over 9 to 12 (228.60 to 304.80), incl	+ 1½ , – 0 (+ 38.10)	+ 2, – 0 (+ 50.80)
Machine Cut After Machine Straightening		
To 3 (76.20), incl	+ ⅛ , – 0 (+ 3.18)	+ 3⁄16 , – 0 (+ 4.76)
Over 3 to 6 (76.20 to 152.40), incl	+ 3⁄16 , – 0 (+ 4.76)	+ ¼ , – 0 (+ 6.35)
Over 6 to 9 (152.40 to 228.60), incl	+ ¼ , – 0 (+ 6.35)	+ 5⁄16 , – 0 (+ 7.94)
Over 9 to 12 (228.60 to 304.80), incl	+ ½ , – 0 (+ 12.70)	+ ½ , – 0 (+ 12.70)

TABLE 11 Camber for Hot-Rolled and Cold-Finished Titanium Bars for Machining

NOTE 1—Camber is the greatest deviation of a side from a straight line. Measurement is taken on the concave side of the bar with a straightedge. Unless otherwise specified, hot-rolled and cold-finished bars for machining purposes are furnished machine straightened to the tolerances specified in this table.

	Tolerance
Hot rolled	⅛ in. (3.18 mm) in any 5 ft (1524 mm), but may not exceed $\frac{⅛ \times \text{No. of ft in length}}{5}$
Cold finished	1/16 in. (1.59 mm) in any 5 ft (1524 mm), but may not exceed $\frac{1/16 \times \text{No. of ft in length}}{5}$