

Submitted for recognition as an American National Standard

Issued APR 1981
Revised MAR 1994
Superseding AMS 4905A

TITANIUM ALLOY, DAMAGE-TOLERANT GRADE PLATE
6Al - 4V
Beta Annealed

UNS R56400

1. SCOPE:

1.1 Form:

This specification covers one type of titanium alloy plate in the beta-annealed condition.

1.2 Application:

This plate has been used typically for parts in damage-tolerant, stress-corrosion-resistant applications requiring strength up to 750 °F (399 °C), but usage is not limited to such applications.

1.3 Safety-Hazardous Materials:

While the materials, methods, applications, and processes described or referenced in this specification may involve the use of hazardous materials, this specification does not address the hazards which may be involved in such use. It is the sole responsibility of the user to ensure familiarity with the safe and proper use of any hazardous materials and to take necessary precautionary measures to ensure the health and safety of all personnel involved.

2. APPLICABLE DOCUMENTS:

The following publications form a part of this specification to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order.

SAE Technical Standards Board Rules provide that: "This report is published by SAE to advance the state of technical and engineering sciences. The use of this report is entirely voluntary, and its applicability and suitability for any particular use, including any patent infringement arising therefrom, is the sole responsibility of the user."

SAE reviews each technical report at least every five years at which time it may be reaffirmed, revised, or cancelled. SAE invites your written comments and suggestions.

2.1 SAE Publications:

Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

AMS 2242 Tolerances, Corrosion and Heat Resistant Steel, Iron Alloy,
Titanium, and Titanium Alloy Sheet, Strip, and Plate

MAM 2242 Tolerances, Metric, Corrosion and Heat Resistant Steel, Iron Alloy,
Titanium, and Titanium Alloy Sheet, Strip, and Plate

AMS 2249 Chemical Check Analysis Limits, Titanium and Titanium Alloys

AMS 2631 Ultrasonic Inspection, Titanium and Titanium Alloy Bar and Billet

AMS 2750 Pyrometry

AMS 2809 Identification, Titanium and Titanium Alloy Wrought Products

2.2 ASTM Publications:

(R)

Available from ASTM, 1916 Race Street, Philadelphia, PA 19103-1187.

ASTM E 8 Tension Testing of Metallic Materials

ASTM E 8M Tension Testing of Metallic Materials (Metric)

ASTM E 120 Chemical Analysis of Titanium and Titanium Alloys

ASTM E 399 Plane Strain Fracture Toughness of Metallic Materials

ASTM E 1409 Determination of Oxygen in Titanium and Titanium Alloys by the
Inert Gas Fusion Technique

ASTM E 1447 Determination of Hydrogen in Titanium and Titanium Alloys by the
Inert Gas Fusion Thermal Conductivity Method

2.3 U. S. Government Publications:

Available from DODSSP, Subscription Services Desk, Building 4D, 700 Robbins
Avenue, Philadelphia, PA 19111-5094.

MIL-STD-105 Sampling Procedures and Tables for Inspection by Attributes

MIL-STD-163 Steel Mill Products, Preparation for Shipment and Storage

3. TECHNICAL REQUIREMENTS:

3.1 Composition:

(R)

Shall conform to the percentages by weight shown in Table 1, determined by analytical methods in accordance with ASTM E 120, ASTM E 1409, and ASTM E 1447, by spectrochemical methods, or by other analytical methods acceptable to purchaser.

TABLE 1 - Composition

Element	Min	Max
Aluminum	5.60	6.30
Vanadium	3.60	4.40
Iron	--	0.25
Oxygen	--	0.12
Carbon	--	0.05
Nitrogen	--	0.03 (300 ppm)
Hydrogen	--	0.0125 (125 ppm)
Yttrium	--	0.005 (50 ppm)
Residual Elements, each (3.1.1)	--	0.10
Residual Elements, total (3.1.1)	--	0.40
Titanium	remainder	

3.1.1 Determination not required for routine acceptance.

3.1.2 Check Analysis: Composition variations shall meet the requirements of AMS 2249.

3.2 Melting Practice:

(R)

Alloy shall be multiple melted. Melting cycle(s) prior to the final melting cycle shall be made using consumable electrode, electron beam, or plasma arc melting practice(s). The final melting cycle shall be made under vacuum using consumable electrode practice with no alloy additions permitted.

3.3 Condition:

Hot rolled, beta-annealed, descaled, and flattened, having a surface appearance comparable to a commercial corrosion-resistant steel No. 1 finish (see 8.2).

3.4 Beta-Annealing:

Plate shall be beta-annealed by heating to the beta transus temperature ± 50 °F (± 28 °C), holding at the selected temperature within ± 25 °F (± 14 °C) for not less than 30 minutes, and cooling in air. Plate shall then be annealed by heating to 1350 °F ± 25 (732 °C ± 14), holding at heat for not less than two hours, and cooling in air. Pyrometry shall be in accordance with AMS 2750.

3.4.1 Beta transus temperature shall be determined by any method approved by purchaser.

3.4.2 Plate shall be held at temperature for sufficient time to ensure that the most remote section (i.e., mid-thickness position in the center of the plate) is at temperature for at least 30 minutes. Plate shall not be stacked during annealing or air cooling.

3.5 Properties:

Plate shall conform to the following requirements:

- 3.5.1 Tensile Properties: Shall be as specified in Table 2, determined in accordance with ASTM E 8 or ASTM E 8M with the rate of strain maintained at 0.003 to 0.007 inch/inch/minute (0.003 to 0.007 mm/mm/minute) through the yield strength and then increased so as to produce failure in approximately one additional minute. When a dispute occurs between purchaser and vendor over the yield strength values, a referee test shall be performed on a machine having a strain rate pacer, using a rate of 0.005 inch/inch/minute (0.005 mm/mm/minute) through the yield strength and a minimum cross-head speed of 0.10 inch per minute (0.04 mm/s) above the yield strength.

TABLE 2A - Minimum Tensile Properties, Inch/Pound Units

Nominal Thickness Inches	Tensile Strength ksi	Yield Strength at 0.2% Offset ksi	Elongation in 2 Inches or 4D Long. and Trans. %
0.1875 to 0.500, incl	130	115	10.0
Over 0.500 to 1.000, incl	127	112	10.0
Over 1.000 to 2.000, incl	125	108	8.0
Over 2.000 to 4.000, incl	122	108	8.0

TABLE 2B - Minimum Tensile Properties, SI Units

Nominal Thickness Millimeters	Tensile Strength MPa	Yield Strength at 0.2% Offset MPa	Elongation in 50.8 mm or 4D Long. and Trans. %
4.762 to 12.70, incl	896	793	10.0
Over 12.70 to 25.40, incl	876	772	10.0
Over 25.40 to 50.80, incl	862	745	8.0
Over 50.80 to 101.60, incl	841	745	8.0

- 3.5.1.1 The results of tensile tests on each lot shall show a maximum difference between the transverse and longitudinal directions of 6.00 ksi (41.4 MPa) for the tensile strength and the yield strength.

- 3.5.2 Fracture Toughness: Plate 0.50 inch (12.7 mm) and over in nominal thickness shall meet a K_{IC} or K_Q not lower than 85 ksi $\sqrt{\text{inch}}$ (93 MPa \sqrt{m}), determined in accordance with ASTM E 399 using the compact tension specimen with the "W" dimension specified in Table 3; plate may be machined not more than 0.010 inch (0.25 mm) on each face.

TABLE 3 - Fracture Toughness, Specimen Dimension

Plate Thickness Inches	Plate Thickness mm	W Inches	W mm
0.500 to 1.000, incl	12.70 to 25.40, incl	5.0	127
Over 1.000	Over 25.40	3.0	76

- 3.5.2.1 Post-test Validity Verification for Specimen: In order to establish a measured level of K_Q as a valid K_{IC} value, all of the validity criteria of ASTM E 399 shall be satisfied. Otherwise, the value reported shall be K_Q .
- 3.5.2.2 Test Data: At the time of testing, the following data shall be recorded on the load-displacement test record:
- Date
 - Specimen identification
 - Load scale calibration (pounds per inch (kN/m) chart)
 - Maximum stress intensity (K , maximum) during final pre-cracking
 - Displacement scale calibration (inch per inch (mm/mm) chart)
 - Loading rate in terms of K_I in accordance with ASTM E 399
 - P_Q , pounds (kN)
 - P_{max} , pounds (kN)
 - Temperature
 - Relative humidity
 - Testing laboratory
 - Test machine
 - Operator
- 3.5.2.3 Reduction of Test Data: Test data shall be reduced as specified in ASTM E 399 to calculate a K_Q value and to determine if a valid K_{IC} property value has been measured. Tensile coupons shall be provided for validity verification wherever fracture toughness coupons are called out. In checking for validity, the yield strength value used shall be the yield strength measured for the same plate from which the fracture toughness specimen was taken. One or more transverse (T-L) tensile specimens taken immediately adjacent to the location of the fracture toughness specimen is required.
- 3.5.2.4 Invalid Test Results: If a value of K_Q is invalid solely on the basis of either of the following criteria, (1) $B < 2.5(K_Q/TYS)^2$, or (2) $P_{max}/P_Q > 1.10$, then such value K_Q may be compared to the minimum level specified in 3.5.2 for qualification purposes. Otherwise (i.e., in the case of a K_Q value invalid on the basis of other ASTM E 399 criteria - e.g., crack front curvature, etc), a minimum of a single retest shall be required.

- 3.5.3 Stress-Corrosion Resistance: Plate shall be tested in the transverse (T-L) direction to determine the K_{SL} value in accordance with 3.5.3.1. The target value for K_{SL} shall be 60.0 ksi $\sqrt{\text{inch}}$ (66 MPa $\sqrt{\text{m}}$) until sufficient data are available to permit establishing a required value.
- 3.5.3.1 Stress-Corrosion Resistance Testing: This testing procedure covers the determination of fracture toughness for Ti-6Al-4V beta-processed plate in an environment of 3.5% NaCl solution in distilled water.
- 3.5.3.1.1 List of Terms:
- K = A stress intensity factor derived from fracture mechanics
- K_{SL} = A stress intensity factor sustained at a specified level for 20 minutes in aqueous 3.5% NaCl
- B = Specimen thickness
- W = Specimen width
- a = Total crack length (sum of notch and fatigue crack length)
- 3.5.3.1.2 Apparatus: Stress-corrosion test apparatus shall meet the requirements of ASTM E 399 for compact tension specimens with the addition of a salt water reservoir.
- 3.5.3.1.3 Test Specimen: Compact tension specimens shall be prepared in accordance with 3.5.2. The specimens shall be pre-cracked in accordance with ASTM E 399. Post-test examination shall be made to ensure that the crack front (as pre-cracked) meets the criteria of ASTM E 399.
- 3.5.3.1.4 Test Procedures:
- 3.5.3.1.4.1 Calculate the load required to develop $K_{SL} = 60 \text{ ksi } \sqrt{\text{inch}}$ (66 MPa $\sqrt{\text{m}}$) using the calculations for compact tension specimens of ASTM E 399.
- 3.5.3.1.4.2 Assemble a salt water reservoir enclosing the pre-cracked area. Fill the reservoir with salt water, making sure that the crack tip is completely immersed.
- 3.5.3.1.4.3 Load the specimen to $K_{SL} = 60 \text{ ksi } \sqrt{\text{inch}}$ (66 MPa $\sqrt{\text{m}}$) at a load rate in terms of K_I in accordance with ASTM E 399. Hold the load at K_{SL} for 20 minutes. If the specimen has not failed after 20 minutes at K_{SL} , raise the load at the same rate as used initially until fracture.
- 3.5.3.1.4.4 Calculate K at fracture in accordance with ASTM E 399.

3.5.5 Microstructure: The microstructure shall be uniform and consist of basketweave or Widmanstätten morphology and shall not contain primary or equiaxed alpha phase. Prior beta grains exceeding 0.050 inch (1.27 mm) in width or 0.100 inch (2.54 mm) in length shall constitute no more than 10% of the microstructure when examined at 10 to 50X magnification. A prior beta grain is a region of basketweave morphology that has transformed from a single beta grain. One microstructural determination shall be made for each lot. The specimen surface shall be parallel to the rolling direction and perpendicular to the plate surface (transverse section). Examination shall be made by traversing the entire thickness of the plate at 500X magnification. Etching shall be by immersion in Kroll's etch (2% hydrofluoric acid, 10% nitric acid, 88% water) for approximately 15 seconds with a water rinse followed by immersion in 0.5% hydrofluoric acid solution for 5 to 10 seconds. A photograph of the typical microstructure at the center and both surfaces of the plate shall be taken at 200X magnification and one photograph at 10 to 50X magnification showing representative microstructure.

3.5.6 Surface Contamination: Plate shall be free of any oxygen-rich layer, such as alpha case, or other surface contamination, determined by microscopic examination at 200X magnification on both plate faces.

3.6 Quality:

Plate, as received by purchaser, shall be uniform in quality and condition, sound, and free from "oil cans" of depth in excess of the flatness tolerances, ripples, and foreign materials, and from imperfections detrimental to usage of the plate.

3.6.1 Acceptance criteria shall be in accordance with MIL-STD-105, Inspection Level II, zero defective.

3.6.2 Plate 0.500 to 4.000 inches (12.70 to 101.60 mm), inclusive, in nominal thickness shall meet the Class A1 requirements of AMS 2631. Instruments shall be adjusted to produce a difference in the height of indications from 2/64- and 3/64-inch (0.8- and 1.2-mm) diameter holes in reference standards. Discontinuity indications (noise or hash) shall not exceed 60% of the response from a 3/64-inch (1.2-mm) flat-bottom hole for 0.5 to 1.0 inch (12.7 to 25.4 mm) plate and 70% for 1.0 to 4.0 inch (25.4 to 101.6 mm) plate.

3.7 Tolerances:

Shall conform to the following:

3.7.1 Thickness, Width, Length, and Straightness: All applicable requirements of (R) AMS 2242 or MAM 2242.

3.7.2 Flatness: Flatness tolerance for plate in all widths shall be as agreed upon by purchaser and vendor.

3.7.2.1 Flatness shall be determined from the expression $100H/L$ where "H" is the distance from the straight edge to the plate at the point of greatest separation and "L" is the distance between contact points of a straight edge laid in any direction on the plate. Cold or hot (lower than 1250 °F (677 °C) flattening of plate may be performed if the plate is subsequently stress relieved by holding for 30 minutes at 1250 °F \pm 25 (677 °C \pm 14).

4. QUALITY ASSURANCE PROVISIONS:

4.1 Responsibility for Inspection:

The vendor of plate shall supply all samples for vendor's tests and shall be responsible for performing all required tests. Purchaser reserves the right to sample and to perform any confirmatory testing deemed necessary to ensure that the plate conforms to the requirements of this specification.

4.2 Classification of Tests:

Tests for all technical requirements are acceptance tests and shall be performed on each lot.

4.3 Sampling and Testing:

Shall be in accordance with the following; a lot shall be all plate of the same nominal size from the same heat processed at the same time.

- 4.3.1 Composition: One sample from each heat, except that for hydrogen and oxygen determinations one sample from each lot obtained after thermal and chemical processing is completed.
- 4.3.2 Tensile Properties: One specimen in the longitudinal direction, one specimen in the long-transverse direction, and, for plate over 2.500 inches (63.50 mm) in nominal thickness, one specimen in the short-transverse direction from each plate unless a statistical sampling plan is approved by purchaser. Specimens shall be cut from the mid-thickness (mid-width for short-transverse specimens) of the plate.
- 4.3.3 Fracture Toughness: Two specimens, one each obtained from different locations of the plate, tested in the transverse direction (T-L), from each lot.
- 4.3.4 Stress-Corrosion Resistance: One specimen tested in the transverse direction (T-L) from each lot, unless a statistical sampling plan is agreed upon by purchaser and vendor.
- 4.3.5 Microstructure and Surface Contamination: One or more specimens from each lot.
- 4.3.6 Quality, Dimensions, and Identification: Each plate.