Society of Automotive Engineers, Inc.
400 COMMONWEALTH DRIVE, WARRENDALE, PA. 15096

AEROSPACE MATERIAL SPECIFICATION

AMS 4905

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Revised

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

1. SCOPE:

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

1.2 Application: Primarily for parts in damage-tolerant, stress-corrosion-resistant applications requiring strength up to 750°F (400°C).

2. APPLICABLE DOCUMENTS: The following publications form a part of this specification to the extent specified herein. The latest issue of Aerospace Material Specifications (AMS) shall apply. The applicable issue of other documents shall be as specified in AMS 2350.

2.1 SAE Publications: Available from Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, PA 15096.

2.1.1 Aerospace Material Specifications:

AMS 2242 - Tolerances, 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 2350 - Standards and Test Methods
AMS 2631 - Ultrasonic Inspection of Titanium Alloys

2.2 ASTM Publications: Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

ASTM E8 - Tension Testing of Metallic Materials
ASTM E120 - Chemical Analysis of Titanium and Titanium Alloys
ASTM E146 - Chemical Analysis of Zirconium and Zirconium Alloys
ASTM E385 - Oxygen Content Using a 14-MeV Neutron Activation and Direct Counting Technique
ASTM E399 - Plane Strain Fracture Toughness of Metallic Materials

2.3 U.S. Government Publications: Available from Commanding Officer, Naval Publications and Forms Center, 5801 Tabor Avenue, Philadelphia, PA 19120.

2.3.1 Federal Standards:

Federal Test Method Standard No. 151 - Metals; Test Methods

2.3.2 Military Specifications:

MIL-H-81200 - Heat Treatment of Titanium and Titanium Alloys

2.3.3 Military Standards:

MIL-STD-105 - Sampling Procedures and Tables for Inspection by Attributes
MIL-STD-163 - Steel Mill Products, Preparation for Shipment and Storage

Printed in U.S.A.

3. TECHNICAL REQUIREMENTS:

3.1 Composition: Shall conform to the following percentages by weight, determined by wet chemical methods in accordance with ASTM E120 or by spectrographic methods in accordance with Federal Test Method Standard No. 151, Method 112 except that oxygen shall be determined in accordance with ASTM E385 and hydrogen in accordance with ASTM E146; other analytical methods may be used provided that such methods are approved by the purchaser:

	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 Condition: Hot rolled, beta-annealed, descaled, and flattened, having a surface appearance comparable to a commercial corrosion-resistant steel No. 1 finish.

3.3 Beta-Annealing: Plate shall be beta-annealed by heating to the beta transus temperature +50°F (+30°C), holding at the selected temperature within ±25°F (±15°C) for not less than 30 min., and cooling in air. Plate shall then be annealed by heating to 1350°F ± 25 (730°C ± 15), holding at heat for not less than 2 hr, and cooling in air.

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

3.3.2 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.

3.3.3 Thermal controls and readouts shall be calibrated to an accuracy of ±5°F (±3°C). Temperature control and calibration shall be in accordance with MIL-H-81200.

3.4 Properties: Plate shall conform to the following requirements:

3.4.1 Tensile Properties: Shall be as specified in Table I, determined in accordance with ASTM E8 with the rate of strain maintained at 0.003 - 0.007 in. per in. per min. (0.003 - 0.007 (mm/mm)/min.) through the yield strength and then increased so as to produce failure in approximately 1 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 in. per in. per min. (0.005 (mm/mm)/min.) through the yield strength and a minimum cross-head speed of 0.10 in. (2.5 mm) per min. above the yield strength.

TABLE I

Nominal Thickness Inches	Tensile Strength psi, min	Yield Strength at 0.2% Offset psi, min	Elongation in 2 in. or 4D Long. and Trans. %, min
0.1875 - 0.500, incl	130,000	115,000	10.0
Over 0.500 - 1.000, incl	127,000	112,000	10.0
Over 1.000 - 2.000, incl	125,000	108,000	8.0
Over 2.000 - 4.000, incl	122,000	108,000	8.0

TABLE I (SI)

Nominal Thickness Millimetres	Tensile Strength MPa, min	Yield Strength at 0.2% Offset MPa, min	Elongation in 50 mm or 4D Long. and Trans. %, min
4.75 to 12.50, incl	896	793	10.0
Over 12.50 to 25.00, incl	876	772	10.0
Over 25.00 to 50.00, incl	862	745	8.0
Over 50.00 to 100.00, incl	841	745	8.0

3.4.1.1 The results of tensile tests on each lot shall show a maximum difference between the transverse and longitudinal directions of 6000 psi (41.4 MPa) for the tensile strength and the yield strength.

3.4.1.2 Tensile property requirements for plate over 4.000 in. (100 mm) in nominal thickness shall be as agreed upon by purchaser and vendor.

3.4.2 Fracture Toughness: Plate 0.50 in. (12.5 mm) and over in nominal thickness shall meet a K_{IC} or K_Q not lower than 85 ksi $\sqrt{in.}$ (93 MPa $\sqrt{m}$), determined in accordance with ASTM E399 using the compact tension specimen with the "W" dimension specified in Table II; plate may be machined not more than 0.010 in. (0.25 mm) on each face.

TABLE II

Plate Thickness Inches	Plate Thickness (Millimetres)	W Inches	W (Millimetres)
0.500 - 1.000, incl	(12.50 - 25.00, incl)	5.0	(125)
Over 1.000	(Over 25.00)	3.0	(75)

3.4.2.1 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 E399 shall be satisfied. Otherwise, the value reported shall be K_Q.

3.4.2.2 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 (lb per in. (kN/m) chart)
Maximum stress intensity (K_f max) during final pre-cracking
Displacement scale calibration (in. per in. (mm/mm) chart)
Loading rate in terms of K_I in accordance with ASTM E399
P_Q, lb (kN)
P_{max}, lb (kN)
Temperature
Relative humidity
Testing laboratory
Test machine
Operator

3.4.2.3 Reduction of Test Data: Test data shall be reduced as specified in ASTM E399 to calculate a K_Q value and to determine if a valid K_{IC} property value has been measured. Tensile test 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. A minimum of one transverse (T-L) tensile specimen taken immediately adjacent to the location of the fracture toughness specimen is required.

3.4.2.4 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 3.4.2 for qualification purposes. Otherwise (i.e., in the case of a K_Q value invalid on the basis of other ASTM E399 criteria - e.g., crack front curvature, etc), a minimum of a single retest shall be required.

3.4.3 Stress-Corrosion Resistance: Plate shall be tested in the transverse (T-L) direction to determine the K_{SL} value in accordance with 3.4.3.1 The target value for K_{SL} shall be 60,000 psi $\sqrt{in.}$ (66 MPa $\sqrt{m}$) until sufficient data are available to permit establishing a required value.

3.4.3.1 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.

3.4.3.1.1 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 min. in aqueous 3.5% NaCl

B = Specimen thickness

W = Specimen width

a = Total crack length (sum of notch and fatigue crack length)

3.4.3.1.2 Apparatus: Stress-corrosion test apparatus shall meet the requirements of ASTM E399 for compact tension specimens with the addition of a salt water reservoir.

3.4.3.1.3 Test Specimen: Compact tension specimens shall be prepared in accordance with 3.4.2. The specimens shall be precracked in accordance with ASTM E399. Post-test examination shall be made to ensure that the crack front (as precracked) meets the criteria of ASTM E399.

3.4.3.1.4 Test Procedures:

3.4.3.1.4.1 Calculate the load required to develop K_{SL} = 60 ksi $\sqrt{in.}$ (66 MPa $\sqrt{m}$), using the calculations for compact tension specimens of ASTM E399.

3.4.3.1.4.2 Assemble a salt water reservoir enclosing the precracked area. Fill the reservoir with salt water, making sure that the crack tip is completely immersed.

3.4.3.1.4.3 Load the specimen to K_{SL} = 60 ksi $\sqrt{in.}$ (66 MPa $\sqrt{m}$) at a load rate in terms of K_I in accordance with ASTM E399. Hold the load at K_{SL} for 20 minutes. If the specimen has not failed after 20 min. at K_{SL}, raise the load at the same rate as used initially until fracture.

3.4.3.1.4.4 Calculate K at fracture in accordance with ASTM E399.

3.4.5 Microstructure: The microstructure shall be uniform and consist of basketweave or Widmanstatten morphology and shall not contain primary or equiaxed alpha phase. Prior beta grains exceeding 0.050 in. (1.25 mm) in width or 0.100 in. (2.50 mm) in length shall constitute no more than 10% of the microstructure when examined at 10 - 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 a magnification of 500X. Etching shall be by immersion in Kroll's etch (2% hydrofluoric acid, 10% nitric acid, 88% water) for approximately 15 sec with a water rinse followed by immersion in 0.5% hydrofluoric acid solution for 5 - 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 - 50X magnification showing representative microstructure.

3.4.6 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.

3.5 Quality:

3.5.1 Alloy shall be multiple melted; the final melting cycle shall be under vacuum. The first melt shall be made by either consumable or nonconsumable electrode practice. The subsequent melt or melts shall be made using consumable electrode practice.

3.5.1.1 The atmosphere for nonconsumable electrode melting shall be vacuum or shall be inert gas at a pressure not higher than 250 mm of mercury.

3.5.1.2 The electrode tip for nonconsumable electrode melting shall be either graphite or water-cooled copper.

3.5.2 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 internal and external imperfections detrimental to usage of the plate. Acceptance criteria shall be in accordance with MIL-STD-105, Inspection Level II, Acceptance Quality Level 1.5%.

3.5.3 Plate 0.500 to 4.000 in. (12.50 to 100.00 mm), incl, 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- in. (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-in. (1.2 mm) flat-bottom hole for 0.5 to 1.0 in. (12.5 - 25 mm) plate and 70% for 1.0 to 4.0 in. (25 to 100 mm) plate.

3.6 Tolerances: Unless otherwise specified, tolerances shall conform to the following:

3.6.1 Thickness, Width, Length, and Straightness: All applicable requirements of AMS 2242.

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

3.6.2.1 Flatness shall be determined from the expression 100H/L where "L" is the distance between contact points of a straight edge laid in any direction on the plate and "H" is the distance from the straight edge to the plate at the point of greatest separation. Cold or hot (lower than 1250°F (675°C)) flattening of plate may be performed if the plate is subsequently stress relieved by holding for 30 min. at 1250°F ± 25 (675°C ± 15).

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. Results of such tests shall be reported to the purchaser as required by 4.4. Purchaser reserves the right to sample and to perform such confirmatory testing as he deems necessary to ensure that the plate conforms to the requirements of this specification.

4.2 Classification of Tests: Tests to determine conformance to all technical requirements of this specification are classified as acceptance tests and shall be performed on each lot.

4.3 Sampling: Shall be as follows; a lot shall be all plate of the same nominal size from the same heat produced at the same time and presented for vendor's inspection at one 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 in. (62.50 mm) in nominal thickness, one specimen in the short-transverse direction from each plate until such time as 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 until such time as a statistical sampling plan is agreed upon by purchaser and vendor.

4.3.5 Microstructure and Surface Contamination: At least one specimen from each lot.

4.3.6 Quality, Dimensions and Tolerances, and Identification: Each plate.

4.4 Reports: