AEROSPACE MATERIAL SPECIFICATION

AMS4905	REV. E

Issued 2000-07
Revised 2014-03

Superseding AMS4905D

Titanium Alloy, Damage-Tolerant Grade Plate
6Al - 4V
Beta Annealed
(Composition similar to UNS R56400)

RATIONALE

AMS4905E results from a Five Year Review and update of this specification to restrict material to the sizes of the mechanical property tables (1.1), to require vacuum in the first consumable electrode melt (3.2) and agreement of mechanical property values on material outside specification ranges (3.5.1.2 and 8.5), and includes ultrasonic testing of all plate 0.500 inch (12.70 mm) and over (3.6.1), adds AS6279 (3.8) and revises the report paragraph (4.4).

1. SCOPE

1.1 Form

This specification covers one type of titanium alloy plate in the beta-annealed condition of plate up through 4.000 inches (101.60 mm) inclusive in thickness (See 8.5).

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 Classification

Products shall be of the following conditions:

1.3.1 Type I - Air Cooled

Product cooled from secondary anneal in accordance with 3.4.2.1 and meeting stress-corrosion resistance requirements of 3.5.3.

1.3.2 Type II - Slow Cooled

Product cooled from secondary anneal in accordance with 3.4.2.2. Stress-corrosion resistance requirements of 3.5.3 are not applicable.

1.3.3 When no type is specified, Type I shall be supplied.

TO PLACE A DOCUMENT ORDER: **Tel: 877-606-7323 (inside USA and Canada)**
Tel: +1 724-776-4970 (outside USA)
Fax: 724-776-0790
Email: CustomerService@sae.org
SAE WEB ADDRESS: **http://www.sae.org**

SAE values your input. To provide feedback on this Technical Report, please visit
http://www.sae.org/technical/standards/AMS4905E

1.4 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 that 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.

1.5 Stress Corrosion

Certain processing procedures and service conditions may cause these products to become subject to stress-corrosion cracking; ARP982 recommends practices to minimize such conditions.

2. APPLICABLE DOCUMENTS

The issue of the following documents in effect on the date of the purchase order forms a part of this specification to the extent specified herein. The supplier may work to a subsequent revision of a document unless a specific document issue is specified. When the referenced document has been cancelled and no superseding document has been specified, the last published issue of that document shall apply.

2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

AMS2242 Tolerances, Corrosion and Heat Resistant Steel, Iron Alloy, Titanium, and Titanium Alloy Sheet, Strip, and Plate

AMS2249 Chemical Check Analysis Limits, Titanium and Titanium Alloys

AMS2631 Ultrasonic Inspection, Titanium and Titanium Alloy Bar and Billet

AMS2750 Pyrometry

AMS2809 Identification, Titanium and Titanium Alloy Wrought Products

AS6279 Industry Standard Practices for Production, Distribution, and Procurement of Metal Stock

2.2 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM E 8 / E 8M Tension Testing of Metallic Materials

ASTM E 399 Linear-Elastic Plane Strain Fracture Toughness K_{IC} of Metallic Materials

ASTM E 539 Analysis of Titanium Alloys by X-Ray Fluorescence Spectrometry

ASTM E 1409 Determination of Oxygen and Nitrogen 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/Infrared Detection Method

ASTM E 1941 Determination of Carbon in Refractory and Reactive Metals and Their Alloys by Combustion Analysis

ASTM E 2371 Analysis of Titanium and Titanium Alloys by Direct Current Plasma and Inductively Coupled Atomic Emission Spectrometry

3. TECHNICAL REQUIREMENTS

3.1 Composition

Shall conform to the percentages by weight shown in Table 1; carbon shall be determined in accordance with ASTM E 1941, hydrogen in accordance with ASTM E 1447, oxygen and nitrogen in accordance with ASTM E 1409, and other elements in accordance with ASTM E 539 or ASTM E 2371. Other analytical methods may be used if acceptable to the 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 (3.1.3)	--	0.0125	(125 ppm)
Yttrium	--	0.005	(50 ppm)
Other Elements, each (3.1.1)	--	0.10	
Other 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 applicable requirements of AMS2249.

3.1.3 Sample size, when using ASTM E 1447, may be as large as 0.35 gram.

3.2 Melting Practice

Alloy shall be multiple melted. The first melt shall be made by vacuum consumable electrode, nonconsumable electrode, electron beam cold hearth, or plasma arc cold hearth melting practice. The subsequent melt or melts shall be made under vacuum using vacuum arc remelting (VAR) practice. Alloy additions are not permitted in the final melt cycle.

3.2.1 The atmosphere for non-consumable electrode melting shall be vacuum or shall be argon and/or helium at an absolute pressure not higher than 1000 mm of mercury.

3.2.2 The electrode for nonconsumable electrode melting shall be water-cooled copper.

3.3 Condition

Hot rolled, beta-annealed, secondary annealed, descaled, and flattened, having a surface appearance comparable to a commercial corrosion-resistant steel No. 1 finish (See 8.2). Plate product shall be produced using standard industry practices designed strictly for the production of plate stock to the procured thickness. Bar, billet, forgings, or forging stock shall not be substituted for plate.

3.4 Annealing

3.4.1 Plate shall be beta-annealed by heating to the beta transus temperature plus 50 °F (28 °C), holding at the selected temperature within ±25 °F (±14 °C) for not less than 30 minutes, and cooling in air to below 1000 °F (538 °C). Plate shall not be stacked during beta-annealing or air cooling.

3.4.2 Secondary Annealing

3.4.2.1 Type I Product Secondary Annealing

After beta-annealing in accordance with 3.4.1, plate shall then be annealed by heating to 1350 °F ± 25 (732 °C ± 14), holding at temperature for not less than 2 hours, and air cooling.

3.4.2.2 Type II Product Secondary Annealing

After beta-annealing in accordance with 3.4.1, plate shall then be annealed by heating to 1350 °F ± 25 (732 °C ± 14), holding at temperature for not less than 2 hours, and slow cooling at a rate not faster than 100 °F per hour (56 °C per hour) to meet the requirements of 3.5 except 3.5.3.

3.4.3 Pyrometry shall be in accordance with AMS2750

3.4.4 Beta transus temperature shall be determined by any method acceptable to purchaser.

3.4.5 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.

3.5 Properties

Plate shall conform to the following requirements after all thermo-mechanical processing (including any flattening or stress relief in accordance with 3.7) is completed:

3.5.1 Tensile Properties

Shall be as specified in Table 2, determined in accordance with ASTM E 8 / E 8M with the rate of strain set at 0.005 inch/inch/minute (0.005 mm/mm/minute) and maintained within a tolerance of ± 0.002 inch/inch/minute (0.002 mm/mm/minute) through the 0.2% offset yield strain.

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
Over 0.500 to 1.000, incl	127	112	10
Over 1.000 to 2.000, incl	125	108	8
Over 2.000 to 4.000, incl	122	108	8

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
Over 12.70 to 25.40, incl	876	772	10
Over 25.40 to 50.80, incl	862	745	8
Over 50.80 to 101.60, incl	841	745	8

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.

3.5.1.2 Mechanical property requirements for product outside the size range covered by Table 2 shall be agreed upon between purchaser and producer.

3.5.2 Fracture Toughness

Plate 0.500 inch (12.70 mm) and over in nominal thickness shall meet a K_{Ic} or K_Q not lower than 85 ksi $\sqrt{inch}$ (93 MPa $\sqrt{m}$) determined in accordance with ASTM E 399 using the compact tension specimen with the minimum "W" dimension as 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, min	W mm, min
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

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 checking for validity, the yield strength value used shall be the yield strength measured for the same plate that 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 are required (See 8.3.4).

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) $W-a < 2.5 (K_Q/\sigma_{YS})^2$, or (2) $P_{max}/P_Q > 1.10$, or both, 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 (Type I material only)

Plate 0.500 inch (12.70 mm) and greater thickness shall be tested in the transverse (T-L) direction to determine the K_{SL} value in accordance with 3.5.3.1 (See 8.3.4). Acceptance criteria for K_{SL} shall be 60.0 ksi $\sqrt{inch}$ (66 MPa $\sqrt{m}$) for Type I material.

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

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 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 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.

3.5.4 Microstructure

The microstructure shall be uniform and consist of basketweave (Widmanstatten) or colony 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. 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.

3.5.5 Surface Contamination

Plate shall be free of any oxygen-rich layer, such as alpha case, or other surface contamination, determined by microscopic examination at 400X magnification on both place faces.

3.6 Quality

Plate, as received by purchaser, shall be uniform in quality and condition, sound, and free from "oil cans" (See 8.3.3) of depth in excess of the flatness tolerances, ripples, and foreign materials, and from imperfections detrimental to usage of the plate.

3.6.1 Plate 0.500 inch (12.70 mm) and over in nominal thickness shall meet the Class A1 requirements of AMS2631. 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 0.500 to 1.000 inch (12.70 to 25.40 mm) plate and 70% for 1.000 inch (25.40 mm and over plate.

3.7 Tolerances

Shall conform to AMS2242.

3.7.1 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 ± 25 (677 °C ±14).

3.8 Production, distribution, and procurement of metal stock shall comply with AS6279. This requirement becomes effective October 1, 2015.

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 the performance of all required tests. Purchaser reserves the right to sample and to perform any confirmatory testing deemed necessary to ensure that the plate conforms to specified requirements.

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 (See 8.3.4).

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.