AEROSPACE MATERIAL SPECIFICATION

AMS4988™	REV. E
Issued 2003-04 Revised 2023-12 Superseding AMS4988D	

Titanium Alloy Sheet, Strip, and Plate
6Al - 6V - 2Sn
Solution Heat Treated
(Composition similar to UNS R56620)

RATIONALE

AMS4988E results from a Five-Year Review and update of this specification with changes to update wording to prohibit unauthorized exceptions (see 3.5.1.1.4 and 8.4), clarify Bending (see 3.5.1.2), relocate Definitions (see 2.3) and statements regarding data and statistical analysis (see 3.5.1.1.3 and 3.5.2.1.2), update Applicable Documents (see Section 2), and Ordering Information (see 8.5).

1. SCOPE

1.1 Form

This specification covers a titanium alloy in the form of sheet, strip, and plate in thicknesses up to 4.000 inches (101.60 mm), inclusive (see 8.5).

1.2 Application

This material has been used typically for parts to be formed or machined in the solution heat-treated condition and subsequently precipitation heat treated requiring high strength-to-weight ratio and stability up to 550 °F (288 °C) in the precipitation heat-treated condition, but usage is not limited to such applications.

1.3 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.

TO PLACE A DOCUMENT ORDER: **Tel: 877-606-7323 (inside USA and Canada)**
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For more information on this standard, visit
https://www.sae.org/standards/content/AMS4988E

2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (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

AMS2368 Sampling and Testing of Wrought Titanium Raw Material, Except Forgings and Forging Stock

AMS2631 Ultrasonic Inspection, Titanium and Titanium Alloy Bar, Billet, and Plate

AMS2750 Pyrometry

AMS2809 Identification, Titanium and Titanium Alloy Wrought Products

ARP982 Minimizing Stress-Corrosion Cracking in Wrought Titanium Alloy Products

AS1814 Terminology for Titanium Microstructures

AS4194 Sheet and Strip Surface Finish Nomenclature

AS6279 Standard Practice for Production, Distribution, and Procurement of Metal Stock

AS7766 Terms Used in Aerospace Metals Specifications

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 A480/A480M General Requirements for Flat-Rolled Stainless and Heat-Resisting Steel Plate, Sheet, and Strip

ASTM E8/E8M Tension Testing of Metallic Materials

ASTM E112 Determining Average Grain Size

ASTM E290 Bend Testing of Material for Ductility

ASTM E384 Microindentation Hardness of Materials

ASTM E539 Analysis of Titanium Alloys by Wavelength Dispersive X-Ray Fluorescence Spectrometry

ASTM E1409 Determination of Oxygen and Nitrogen in Titanium and Titanium Alloys by Inert Gas Fusion

ASTM E1447 Determination of Hydrogen in Reactive Metals and Reactive Metal Alloys by Inert Gas Fusion with Detection by Thermal Conductivity or Infrared Spectrometry

ASTM E1941 Determination of Carbon in Refractory and Reactive Metals and Their Alloys by Combustion Analysis

ASTM E2371 Analysis of Titanium and Titanium Alloys by Direct Current Plasma and Inductively Coupled Plasma Atomic Emission Spectrometry (Performance-Based Test Methodology)

ASTM E2994 Analysis of Titanium and Titanium Alloys by Spark Atomic Emission Spectrometry and Glow Discharge Atomic Emission Spectrometry (Performance-Based Method)

2.3 Definitions

Terms used in AMS are defined in AS7766 and as follows:

2.3.1 OIL CAN

An excess of material in a localized area of a sheet that causes the sheet to buckle in that area. When the sheet is placed on a flat surface and hand pressure applied to the buckle, the buckle will spring through to the opposite surface or spring up in another area of the sheet.

2.3.2 Terminology relating to titanium microstructures is presented in AS1814.

2.3.3 Commercial corrosion-resistant steel finishes are defined in ASTM A480/A480M and AS4194.

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 E1941, hydrogen in accordance with ASTM E1447, oxygen and nitrogen in accordance with ASTM E1409, and other elements in accordance with ASTM E539, ASTM E2371, or ASTM E2994. Other analytical methods may be used if acceptable to the purchaser.

Table 1 - Composition

Element	Min	Max	
Aluminum	5.00	6.00	
Vanadium	5.00	6.00	
Tin	1.50	2.50	
Iron	0.35	1.00	
Copper	0.35	1.00	
Oxygen	--	0.20	
Carbon	--	0.05	
Nitrogen	--	0.04	(400 ppm)
Hydrogen	--	0.015	(150 ppm)
Yttrium (3.1.1)	--	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.

3.2 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. Subsequent melt or melts shall be made using vacuum arc remelting (VAR) practice. Alloy additions are not permitted in the final (VAR) melt

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 tip for nonconsumable electrode melting shall be water-cooled copper.

3.3 Condition

The product shall be supplied in the following condition:

3.3.1 Sheet and Strip

Hot rolled, with or without subsequent cold reduction, solution heat treated, descaled, and leveled, having a surface appearance comparable to a commercial corrosion-resistant steel No. 2D finish (see 2.3.3).

3.3.2 Plate

Hot rolled, solution heated, and flattened, having a surface appearance comparable to a commercial corrosion-resistant steel No. 1 finish (see 2.3.3). 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 supplied in lieu of plate.

3.4 Heat Treatment

The product shall be solution heat treated as follows; pyrometry shall be in accordance with AMS2750:

3.4.1 Sheet, strip and plate shall be solution heat treated by heating to a temperature within the range 1550 to 1700 °F (843 to 927 °C), holding at selected temperature within ±25 °F (±14 °C) for 2 to 60 minutes, and quenching in agitated water. Air cooling may be applied in thin material.

3.4.2 Continuous Solution Heat treatment of Sheet and Strip

When continuous solution heat treatment is used, process parameters (e.g., furnace temperature set points, heat input, travel rate, etc.) for continuous heat-treating lines shall be established by the material producer and validated by testing of product to requirements of 3.5.

3.5 Properties

Product shall conform to the following requirements:

3.5.1 As Solution Heat Treated

3.5.1.1 Tensile Properties

Shall be as specified in Table 2, determined in accordance with ASTM E8/E8M with the rate of strain set at 0.005 in/in/min (0.005 mm/mm/min) and maintained within a tolerance of ±0.002 in/in/min (±0.002 mm/mm/min) through the 0.2% offset yield strain.

Table 2A - Tensile properties, inch/pound units (see 3.5.1.1.3)

Nominal Thickness Inches	Tensile Strength ksi	Yield Strength at 0.2% Offset ksi, Max	Elongation in 2 Inches or 4D %, Min
Up to 0.1875, excl	(3.5.1.1.1)	160	10 (3.5.1.1.2)

Table 2B - Tensile properties, SI units (see 3.5.1.1.3)

Nominal Thickness Millimeters	Tensile Strength MPa	Yield Strength at 0.2% Offset MPa, Max	Elongation in 50.8 mm or 4D %, Min
Up to 4.76, excl	(3.5.1.1.1)	1103	10 (3.5.1.1.2)

3.5.1.1.1 Spread between tensile strength and yield strength shall be 15 ksi (103 MPa) minimum.

3.5.1.1.2 For thickness under 0.025 inch (0.64 mm), elongation values shall be as agreed upon.

3.5.1.1.3 The mechanical properties have been taken from MIL-T-9046 and have not been substantiated by AMS statistical procedures.

3.5.1.1.4 Mechanical property requirements for product outside the range covered by 1.1 shall be agreed upon between purchaser and producer and reported per 4.4.2 (see 8.5).

3.5.1.2 Bending

Product under 0.1875 inch (4.762 mm) in nominal thickness, shall have a test sample prepared nominally 0.750 inch (19.06 mm) in width, with its axis of bending parallel to the direction of rolling. The sample shall be bend tested in conformance with the guided bend test defined in ASTM E290 through an angle of 105 degrees. The test fixture supports shall have a contact radius 0.010-inch (0.254-mm) minimum, and the plunger shall have a radius equal to the bend factor shown in Table 3 times the nominal thickness. Examination of the bent sample shall show no evidence of cracking when examined at 15 to 25X magnification.

Table 3 - Bend factor

Nominal Thickness Inches	Nominal Thickness Millimeters	Bend Factor
Up to 0.070, excl	Up to 1.78, excl	4
0.070 to 0.1875, excl	1.78 to 4.762, excl	4.5

3.5.1.3 Microstructure

Shall be that structure resulting from processing within the alpha-beta phase field. Microstructure shall conform to 3.4.1.3.1 (see 2.3.2).

3.5.1.3.1 Equiaxed and/or elongated primary alpha in a transformed beta matrix with no continuous network of alpha at prior beta grain boundaries.

3.5.1.3.2 A microstructure showing a continuous network of alpha in prior beta grain boundaries is not acceptable.

3.5.1.4 Surface Contamination

The product shall be free of any oxygen-rich layer, such as alpha case, or other surface contamination, determined as in any one of the following: 3.5.1.4.1, 3.5.1.4.2, 3.5.1.4.3, or other method acceptable to purchaser.

3.5.1.4.1 The bend test of 3.5.1.2.

3.5.1.4.2 Examination of a metallographic cross section at 400X minimum magnification.

3.5.1.4.3 Hardness Difference

a surface hardness more than 40 points higher than the subsurface hardness, determined in accordance with ASTM E384 on the Knoop scale using a 200-gram load, being evidence of unacceptable surface contamination.

3.5.1.5 Average Grain Size

Shall be ASTM No. 6 or finer determined in accordance with ASTM E112.

3.5.2 Response to Heat Treatment

Specimens from product shall conform to the following requirements after being precipitation heat treated by heating to a temperature within the range of 875 to 1150 °F (468 to 621 °C), holding at selected temperature within ±15 °F (±8 °C) for 2 to 10 hours, and cooling in air. Precipitation heat treatment shall precede final machining of specimens.

3.5.2.1 Tensile Properties

Shall be as shown in Table 4, determined per 3.5.1.1.

Table 4A - Minimum tensile properties (see 3.5.2.1.2)

Nominal Thickness Inches	Tensile Strength ksi	Yield Strength at 0.2% Offset ksi	Elongation in 2 Inches or 4D %
Up to 0.1875, excl	170	160	8 (6) (see 3.5.2.1.1)
0.1875 to 1.500, excl	170	160	8
1.500 to 2.500, excl	160	150	6
2.500 to 4.000, incl	150	140	6

Table 4B - Minimum tensile properties, SI units (see 3.5.2.1.2)

Nominal Thickness Millimeters	Tensile Strength MPa	Yield Strength at 0.2% Offset MPa	Elongation in 50.8 mm or 4D %
Up to 4.76, excl	1172	1103	8 (6) (see 3.5.2.1.1)
4.76 to 38.10, excl	1172	1103	8
38.10 to 63.50, excl	1103	1034	6
63.50 to 101.60, incl	1034	965	6

3.5.2.1.1 Elongation value in parentheses is for transverse direction only.

3.5.2.1.2 The mechanical properties have been taken from MIL-T-9046 and have not been substantiated by AMS statistical procedures.

3.6 Quality

The product, as received by the purchaser, shall be uniform in quality and condition, sound, and free from “oil cans” (see 2.3.1) of depth in excess of the flatness tolerances, ripples, and foreign materials, and from imperfections detrimental to usage of the product.

3.6.1 Ultrasonic Inspection

3.7 Plate 0.500 inch (12.70 mm) and over in nominal thickness shall meet Class A1 requirements of AMS2631.

3.8 Tolerances

Shall conform to all applicable requirements of AMS2242.

3.9 Production, distribution, and procurement of metal stock shall comply with AS6279.

3.10 Exceptions

3.11 Any exceptions shall be authorized by purchaser and reported as in 4.4.2.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for Inspection

The producer of the product shall supply all samples for the producer's tests and shall be responsible for the performance of all required tests. The purchaser reserves the right to sample and to perform any confirmatory testing deemed necessary to ensure that the product conforms to specified requirements.

4.2 Classification of Tests

All technical requirements are acceptance tests and shall be performed on each heat or lot as applicable.