AEROSPACE MATERIAL SPECIFICATION

AMS4931	REV. E

Issued 1987-01
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Superseding AMS4931D

Titanium Alloy Bars, Forgings, and Rings
6Al - 4V Extra Low Interstitial (ELI)
Duplex Annealed, Fracture Toughness
(Composition similar to UNS R56400)

RATIONALE

AMS4931E results from a Five Year Review and update of this specification that includes the removal of sample size allowance for hydrogen of Table 1 (covered by ASTM E1447), requires agreement on mechanical property values for material outside specification ranges (3.5.1.1.3 and 8.6), adds AS6279 (3.8) and AMS2368 (4.3 and 4.5) and revises the report paragraph (4.4).

1. SCOPE

1.1 Form

This specification covers a titanium alloy in the form of bars 6.000 inches (152.40 mm) and under in nominal diameter or least distance between parallel sides, forgings and flash welded rings 6.000 inches (152.40 mm) and under in thickness, and stock for forging and stock for flash welded rings of any size.

1.2 Application

These products have been used typically for parts requiring a combination of high tensile strength up to 750 °F (399 °C) and high fracture toughness, but usage is not limited to such applications.

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 +1 724-776-4970 (outside USA), www.sae.org.

AMS2241 Tolerances, Corrosion and Heat-Resistant Steel, Iron Alloy, Titanium, and Titanium Alloy Bars and Wire

AMS2249 Chemical Check Analysis Limits, Titanium and Titanium Alloys

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/AMS4931E

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

AMS2750 Pyrometry

AMS2808 Identification Forgings

AMS2809 Identification, Titanium and Titanium Alloy Wrought Products

AMS7498 Rings, Flash Welded, Titanium and Titanium Alloys

AS6279 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 E8/E8M Tension Testing of Metallic Materials

ASTM E399 Linear-Elastic Plane-Strain Fracture Toughness K_{IC} of Metallic Materials

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

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

ASTM E1447 Determination of Hydrogen in Titanium and Titanium Alloys by the Inert Gas Fusion Thermal Conductivity/Infrared Detection Method

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

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 or ASTM E2371. Other analytical methods may be used if acceptable to the purchaser.

Table 1 - Composition

Element	min	max	
Aluminum	5.50	6.50	
Vanadium	3.50	4.50	
Iron	--	0.25	
Oxygen	--	0.130	
Carbon	--	0.08	
Nitrogen	--	0.03	(300 ppm)
Hydrogen (3.1.1)	--	0.0125	(125 ppm)
Yttrium (3.1.2)	--	0.005	(50 ppm)
Other Elements, each (3.1.2)	--	0.10	
Other Elements, total (3.1.2)	--	0.40	
Titanium	remainder		

3.1.1 Hydrogen content of forgings may be as high as 0.0150 (150 ppm).

3.1.2 Determination not required for routine acceptance. If yttrium content is determined, no variation over maximum will be permitted for yttrium.

3.1.3 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. 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 nonconsumable 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 Bars

Hot finished with or without subsequent cold reduction, duplex annealed, and descaled. The product shall be processed to the final thickness/diameter by metallurgical working operations prior to any straightening, dimensional sizing or surface finishing operations. Bar shall not cut from plate.

3.3.2 Forgings and Flash Welded Rings

Duplex annealed and descaled.

3.3.2.1 Flash welded rings shall not be supplied unless specified or permitted on purchaser's part drawing. When supplied, rings shall be manufactured in accordance with AMS7498.

3.3.3 Stock for Forging or Flash Welded Rings

As ordered by the forging or flash welded ring manufacturer.

3.4 Heat Treatment

Bars, forgings, and flash welded rings shall be duplex annealed as follows; pyrometry shall be in accordance with AMS2750:

3.4.1 Solution Anneal

Heat to a temperature within the range 50 to 100 °F (28 to 56 °C) degrees below the beta transus, hold at the selected temperature within ±25 °F (±14 °C) for not less than 1 hour, and cool in air.

3.4.1.1 Beta transus temperature shall be measured with an accuracy of ±15 °F (±8 °C) (See 8.3).

3.4.2 Anneal

Reheat to a temperature within the range 1300 to 1400 °F (704 to 760 °C), hold at the selected temperature within ±25 °F (±14 °C) for not less than 1 hour, and cool in air.

3.5 Properties

The product shall conform to the following requirements:

3.5.1 Bars, Forgings, and Flash Welded Rings

Bars 6.000 inches (152.40 mm) and under in nominal diameter or least distance between parallel sides and forgings and flash welded rings 6.000 inches (152.40 mm) and under in nominal thickness shall conform to the following requirements.

3.5.1.1 Tensile Properties

Shall be as specified in Table 2, determined in accordance with ASTM E8/E8M on specimens as in 4.3.1.2 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 Diameter or Least Distance Between Parallel Sides Inches	Tensile Strength ksi	Yield Strength at 0.2% Offset ksi	Elongation in 4D %			Reduction of Area %		
			Long.	L.T.	S.T.	Long.	L.T.	S.T.
Up to 3.000, incl	125	115	10	10	8	25	20	--
Over 3.000 to 4.000, incl	123	110	10	10	8	20	20	15
Over 4.000 to 6.000, incl	120	110	8	8	6	20	15	15

Note: Long. = Longitudinal
L.T. = Long Transverse
S.T. = Short Transverse

Table 2B - Minimum tensile properties, SI units

Nominal Diameter or Least Distance Between Parallel Sides Millimeters	Tensile Strength MPa	Yield Strength at 0.2% Offset MPa	Elongation in 4D %			Reduction of Area %		
			Long.	L.T.	S.T.	Long.	L.T.	S.T.
Up to 76.20, incl	862	793	10	10	8	25	20	--
Over 76.20 to 101.60, incl	848	758	10	10	8	20	20	15
Over 101.60 to 152.40, incl	827	758	8	8	6	20	15	15

Note: Long. = Longitudinal
L.T. = Long Transverse
S.T. = Short Transverse

3.5.1.1.1 Tensile and yield strength properties apply in both the longitudinal and transverse directions but tests in the transverse direction need be made only on product that a specimen not less than 2.50 inches (63.5 mm) in length can be obtained.

3.5.1.1.2 Specimens for the longitudinal requirements in Table 2 shall be taken with the axis of the specimen approximately parallel to the grain flow for bars and forgings and specimens shall be taken in the circumferential direction from flash welded rings.

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

3.5.1.2 Fracture Toughness

A valid K_{IC} fracture toughness of 70 ksi √inch (77 MPa √m) minimum in accordance with ASTM E399 for all specimen orientations shall be obtained for bars and rings 0.50 inch (12.7 mm) and over in section thickness and forgings in all section thicknesses.

3.5.1.2.1 To facilitate determination of fracture toughness a tensile specimen taken immediately adjacent to the location of the fracture toughness specimen is required. Fracture planes of the tensile and K_{IC} specimen shall be in the same orientation. If a tensile specimen cannot be excised with the fracture plane in the same orientation as that of the fracture toughness specimen, the orientation of the tensile specimen shall be as approved by the purchaser.

3.5.1.2.2 If a K_Q value is invalid solely on the basis of either W-a is less than 2.5 $(K_Q/TYS)^2$ or P_{max}/P_Q is greater than 1.10 and the thickest possible specimen has been used, the K_Q value may be used to satisfy the minimum K_{IC} requirements of 3.5.1.2. K_Q values invalid on the basis of criteria other than those listed above shall not be used to satisfy the minimum K_{IC} requirements of 3.5.1.2, but an additional specimen may be tested as allowed by 4.5.

3.5.1.3 Microstructure

Shall be that structure resulting from processing within the alpha-beta phase field. Microstructure shall conform to 3.5.1.3.1 or 3.5.1.3.2.

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 Essentially complete field of equiaxed and/or elongated alpha with or without intergranular beta and with no continuous network of alpha at prior beta grain boundaries.

3.5.1.4 Surface Contamination

Except as specified by 3.5.1.4.1 and 3.5.1.4.2, the product shall be free of any oxygen-rich layer, such as alpha case, or other surface contamination, determined by microscopic examination at not lower than 400X magnification or other method acceptable to purchaser.

3.5.1.4.1 An oxygen-rich layer (See 8.2) not greater than 0.001 inch (0.025 mm) in depth will be permitted on bars other than rounds.

3.5.1.4.2 When permitted by purchaser, forgings and flash welded rings to be machined all over may have an oxygen-rich layer provided such layer is removable within the machining allowance on the forging or flash welded ring.

3.5.2 Stock for Forging

When a sample of stock is forged to a test coupon, having a degree of mechanical working not greater than the forging, and heat treated as in 3.4, specimens taken from the heat treated coupon shall conform to the requirements of 3.5.1.1 and 3.5.1.2. If specimens taken from the stock after heat treatment as in 3.4 conform to the requirements of 3.5.1.1 and 3.5.1.2, the tests shall be accepted as equivalent to tests of a forged coupon.

3.5.3 Stock for Flash Welded Rings

Specimens taken from stock heat treated as in 3.4 shall conform to the requirements of 3.5.1.1 and 3.5.1.2.

3.6 Quality

The product, as received by purchaser, shall be uniform in quality and condition, sound, and free from foreign materials and from imperfections detrimental to usage of the product.

3.7 Tolerances

Bars shall conform to all applicable requirements of AMS2241.

3.8 Production, distribution, and procurement of metal stock shall comply with AS6279. This requirement becomes effective September 1, 2016.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for Inspection

The producer of the product shall supply all samples for producer'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 product conforms to specified requirements.

4.2 Classification of Tests

4.2.1 Acceptance Tests

The following requirements are acceptance tests and shall be performed on each heat or lot as applicable:

4.2.1.1 Composition (3.1) of each heat.

4.2.1.2 Hydrogen content (3.1), tensile properties (3.5.1.1), fracture toughness (3.5.1.2), microstructure (3.5.1.3), and surface contamination (3.5.1.4) of each lot of bars, forgings, and flash welded rings.

4.2.1.3 Tolerances (3.7) of each lot of bars.

4.2.2 Periodic Tests

Stock for forging (3.5.2) and stock for flash welded rings (3.5.3) to demonstrate ability to develop required properties are periodic tests and shall be performed at a frequency selected by the producer unless frequency of testing is specified by purchaser.

4.3 Sampling and Testing

Shall be in accordance with AMS2368 and the following; a lot shall be all product of the same nominal size from the same heat, processed at the same time, and duplex annealed as a heat treat batch:

4.3.1 For Acceptance Tests

4.3.1.1 Composition

One sample from each heat, except that for hydrogen determinations one sample from each lot obtained after thermal and chemical processing is completed.

4.3.1.2 Tensile Properties

One sample from bars and flash welded rings from each lot. One longitudinal specimen from each lot of forgings from a section having maximum thickness and from a section having minimum thickness.

4.3.1.2.1 Samples from flash welded rings shall be cut from parent metal not including the weld-heat-affected zone.

4.3.1.3 Fracture Toughness

Specimen shall be as thick as practical except when thickness exceeds 1.50 inches (38.1 mm) in which case 1.50 inches (38.1 mm) shall be the minimum thickness. Orientation and number of fracture toughness specimens shall be as agreed upon by purchaser and producer. If forging dimension is inadequate, or when specified by purchaser, a prolongation representative of the forging shall be provided.