SAE Aerospace
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AEROSPACE MATERIAL SPECIFICATION

SAE AMS 4931C

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Superseding AMS 4931B

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

(Composition similar to UNS R56400)

RATIONALE

AMS 4931C results from a Five Year Review and update of this specification.

1. SCOPE

1.1 Form

This specification covers a titanium alloy in the form of bars, forgings, flash welded rings, and stock for forging or flash welded rings.

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

AMS 2241	Tolerances, Corrosion and Heat-Resistant Steel, Iron Alloy, Titanium, and Titanium Alloy Bars and Wire
AMS 2249	Chemical Check Analysis Limits, Titanium and Titanium Alloys
AMS 2750	Pyrometry
AMS 2808	Identification, Forgings
AMS 2809	Identification, Titanium and Titanium Alloy Wrought Products
AMS 7498	Rings, Flash Welded, Titanium and Titanium Alloys

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

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	Tension Testing of Metallic Materials
ASTM E 399	Plane-Strain Fracture Toughness of Metallic Materials
ASTM E 539	X-Ray Emission Spectrometric Analysis of 6Al-4V Titanium Alloy
ASTM E 1409	Determination of Oxygen and Nitrogen in Titanium and Titanium Alloys by the Inert Gas Fusion Method
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
ASTM E 2371	Analysis of Titanium and Titanium Alloys by Atomic Emission Plasma 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	5.50	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) (3.1.2)	--	0.0125	(125 ppm)
Yttrium (3.1.3)	--	0.005	(50 ppm)
Other Elements, each (3.1.3)	--	0.10	
Other Elements, total (3.1.3)	--	0.40	
Titanium	remainder		

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

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

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

3.1.4 Check Analysis

Composition variations shall meet the applicable requirements of AMS 2249.

3.2 Melting Practice

Alloy shall be multiple melted. The final melting cycle shall be under vacuum. 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 using vacuum arc remelting (VAR) practice with no alloy additions permitted in the last vacuum arc remelt.

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 produced using standard industry practices designed strictly for the production of bar stock to the procured size. Cut plate shall not be supplied in lieu of bar.

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 AMS 7498.

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 AMS 2750:

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 one hour, and cool in air.

3.4.1.1 Beta transus temperature shall be measured with an accuracy of ±10 °F (±6 °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 one 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

Product 6.00 inches (152.4 mm) and under in nominal diameter or distance between parallel sides shall conform to the following requirements.

3.5.1.1 Tensile Properties

Shall be as specified in Table 2, determined in accordance with ASTM E 8 on specimens as in 4.3.1.2 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/second) above the yield strength.

TABLE 2A - MINIMUM TENSILE PROPERTIES, INCH/POUND UNITS

Nominal Diameter or 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 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 Longitudinal requirements in Table 2 apply to specimens from bars taken with the axis of the specimen approximately parallel to the grain flow and to specimens taken in the circumferential direction from flash welded rings.

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.

3.5.1.2.1 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 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 Forging Stock

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 freefrom foreign materials and from imperfections detrimental to usage of the product.

3.7 Tolerances

Bars shall conform to all applicable requirements of AMS 2241.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for Inspection

The vendor of the product 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 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

Forging stock (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 vendor unless frequency of testing is specified by purchaser.

4.3 Sampling and Testing

Shall be in accordance with 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 vendor. If forging dimension is inadequate, or when specified by purchaser, a prolongation representative of the forging shall be provided.

4.4 Reports

4.4.1 The vendor of bars, forgings, and flash welded rings shall furnish with each shipment a report showing the results of tests for composition of each heat, and for the hydrogen content, tensile properties, and fracture toughness of each lot, and stating that the product conforms to the other technical requirements. This report shall include the purchase order number, heat and lot numbers, AMS 4931C, product form, size, specific heat treatment used, and quantity. If forgings are supplied, the size and melt source of stock used to make the forgings shall also be included.

4.4.2 The vendor of stock for forging or flash welded rings shall furnish with each shipment a report showing the results of tests for composition of each heat and for the hydrogen content of each lot. This report shall include the purchase order number, heat number, AMS 4931C, size, and quantity.

4.5 Resampling and Retesting

With the exception of fracture toughness, if any specimen used in the above tests fails to meet the specified requirements, disposition of the product may be based on the results of testing three additional specimens for each original nonconforming specimen. Failure of any retest specimen to meet the specified requirements shall be cause for rejection of the product represented. In the case of fracture toughness, a single retest is permitted for any invalidity except as noted in 3.5.1.2.2. Results of all tests shall be reported.