ADOPTION NOTICE

AMS 4931 "Titanium Alloy Bars, Forgings, & Rings, 6Al- 4V, Extra Low Interstitial (ELI), Duplex Annealed, Fracture Toughness" was adopted on 24 June 1994 for use by the Department of Defense (DoD). Proposed changes by DoD activities must be submitted to the DoD Adopting Activity: Air Force, ASC/ENOSD. Building 125, 2335 Seventh Street, Suite 6, Wright-Patterson AFB OH 45433-7809. DoD activities may obtain copies of this standard from the Standardization Document Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia, PA 19111-5094. The private sector and other Government agencies may purchase copies from the Society of Automotive Engineers Inc., 400 Commonwealth Drive, Warrendale, PA 15096-0001.

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Adopting Activity:
Air Force - 11
(Proj No. 9530-0506)

Review activities:
AF - 99

AMSC N/A

FSC 9530

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INTERNATIONAL
400 Commonwealth Drive, Warrendale, PA 15096-0001

AEROSPACE MATERIAL SPECIFICATION

SAE AMS 4931A

Issued 1 JAN 1987
Revised 1 APR 1993
Superseding AMS 4931

Submitted for recognition as an American National Standard

TITANIUM ALLOY BARS, FORGINGS, AND RINGS
6A1 - 4V Extra Low Interstitial (ELI)
Duplex Annealed, Fracture Toughness

UNS R56400

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 following publications form a part of this specification to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order.

2.1 SAE Publications:

Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

AMS 2241 Tolerances, Corrosion and Heat Resistant Steel, Iron Alloy, Titanium, and Titanium Alloy Bars and Wire
MAM 2241 Tolerances, Metric, 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

2.2 ASTM Publications:

Available from ASTM, 1916 Race Street, Philadelphia, PA 19103-1187.

ASTM E 8 Tension Testing of Metallic Materials
ASTM E 8M Tension Testing of Metallic Materials (Metric)
ASTM E 120 Chemical Analysis of Titanium and Titanium Alloys
ASTM E 146 Chemical Analysis of Zirconium and Zirconium Alloys
ASTM E 399 Plane-Strain Fracture Toughness of Metallic Materials

2.3 U.S. Government Publications:

Available from Standardization Documents Order Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

MIL-STD-163 Steel Mill Products, Preparation for Shipment and Storage

3. TECHNICAL REQUIREMENTS:

3.1 Composition:

Shall conform to the percentages by weight shown in Table 1; hydrogen shall be determined in accordance with ASTM E 146; other elements shall be determined by wet chemical methods in accordance with ASTM E 120, by spectrochemical methods, or by other analytical methods acceptable to 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)
Residual Elements, each (3.1.2)	--	0.10
Residual 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 (R) 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 requirements of
(R) AMS 2249.

3.2 Melting Practice:

(R)

Alloy shall be multiple melted. The final melting cycle shall be under vacuum. The first melt shall be made by consumable electrode, nonconsumable electrode, electron beam, or plasma arc melting practice. The subsequent melt or melts shall be made using consumable electrode practice with no alloy additions permitted in the last consumable electrode melt.

3.2.1 The atmosphere for nonconsumable electrode melting shall be vacuum or
(R) 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.

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:

(R)

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 (±I4 °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 ±lO °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 (R) 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 or ASTM E 8M 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/s) above the yield strength.

3.5.1.1.1 (R) 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 from which 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: Specimens as in 4.3.1.3 from bars and rings 0.50 inch (12.7 mm) and over in section thickness and forgings in all section thicknesses, with prolongations if necessary, shall meet a fracture toughness K_{1C} or K_Q not lower than 70.0 ksi $\sqrt{\text{inch}}$ (77 MPa $\sqrt{\text{m}}$), determined in accordance with ASTM E 399.

3.5.1.2.1 Valid K_{1C} values shall be determined in accordance with ASTM E 399. Invalid plane strain fracture toughness (K_Q) values are valid if they are the result of a single invalidity and exceed the minimum K_{1C} acceptance criteria. Failure of both specimen thickness B< 2.5 $(K_Q/TYS)^2$ and the ratio of the applied maximum load divided by the load at the flow dimension (P_{MAX}/P_Q 1.10) shall be treated as a single invalidity. Any other invalidity shall require retesting as in 4.5.

3.5.1.3 (R) Microstructure: Shall be that structure resulting from alpha-beta processing. Microstructure shall conform to 3.5.1.3.1, 3.5.1.3.2, or 3.5.1.3.3:

3.5.1.3.1 (R) Equiaxed alpha in a transformed beta matrix.

3.5.1.3.2 (R) Equiaxed alpha and elongated alpha in a transformed beta matrix.

3.5.1.3.3 (R) Partially broken and distorted grain boundary alpha with plate-like alpha.

3.5.1.3.4 (R) A microstructure showing a continuous network of alpha in prior beta grain boundaries is not acceptable.

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 100X 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 (R) 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 free-from foreign materials and from imperfections detrimental to usage of the product.

3.7 Tolerances:

Bars shall conform to all applicable requirements of AMS 2241 or MAM **2241.**

4. QUALITY ASSURANCE PROVISIONS:

4.1 (R) Responsibility for Inspection:

The vendor of the product shall supply all samples for vendor's tests and shall be responsible for performing all required tests. Purchaser reserves the right to sample and to perform any confirmatory testing deemed necessary to ensure that the product conforms to the requirements of this specification.

4.2 Classification of Tests:

4.2.1 Acceptance Tests: Tests for 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: Tests of 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:

(R) 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.

(R) 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.

4.3.2 For Periodic Tests: As agreed upon by purchaser and vendor.

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 chemical 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 number, AMS 4931A, size, specific heat treatment used, and quantity. If forgings are supplied, the part number and 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 chemical composition of each heat and for the hydrogen content of each lot. This report shall include the purchase order number, heat number, AMS 4931A, size, and quantity.

4.5 Resampling and Retesting:

(R) 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 3.5.1.2.1. Results of all tests shall be reported.

5. PREPARATION FOR DELIVERY:

5.1 Identification:

Shall be as follows:

5.1.1 Bars: In accordance with AMS 2809 as applicable.

5.1.2 Forgings: In accordance with AMS 2808.

5.1.3 Flash Welded Rings and Stock for Forging or Flash Welded Rings: As agreed upon by purchaser and vendor.

5.2 Packaging:

5.2.1 (R) The product shall be prepared for shipment in accordance with commercial practice and in compliance with applicable rules and regulations pertaining to the handling, packaging, and transportation of the product to ensure carrier acceptance and safe delivery.

5.2.2 For direct U.S. Military procurement, packaging shall be in accordance with MIL-STD-163, Commercial Level, unless Level A is specified in the request for procurement.