

**AEROSPACE
MATERIAL
SPECIFICATION**

AMS 4931

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Submitted for recognition as an American National Standard

TITANIUM ALLOY BARS, FORGINGS, AND RINGS
6Al - 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: Primarily for parts requiring strength up to 750°F (400°C) and fracture toughness.

2. APPLICABLE DOCUMENTS: The following publications form a part of this specification to the extent specified herein. The latest issue of Aerospace Material Specifications shall apply. The applicable issue of other documents shall be as specified in AMS 2350.

2.1 SAE Publications: Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096.

2.1.1 Aerospace Material Specifications:

- AMS 2241 - Tolerances, Corrosion and Heat Resistant Steel, Iron Alloy, Titanium, and Titanium Alloy Bars and Wire
- AMS 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 2350 - Standards and Test Methods
- AMS 2375 - Control of Forgings Requiring First Article Approval
- AMS 2808 - Identification, Forgings
- AMS 2809 - Identification, Titanium and Titanium Alloy Wrought Products
- AMS 7498 - Rings, Flash Welded, Titanium and Titanium Alloys

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2.2 ASTM Publications: Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

ASTM E8 - Tension Testing of Metallic Materials
 ASTM E120 - Chemical Analysis of Titanium and Titanium Alloys
 ASTM E146 - Chemical Analysis of Zirconium and Zirconium Alloys
 ASTM E399 - Plane-Strain Fracture Toughness of Metallic Materials

2.3 U.S. Government Publications: Available from Commanding Officer, Naval Publications and Forms Center, 5801 Tabor Avenue, Philadelphia, PA 19120.

2.3.1 Military Specifications:

MIL-H-81200 - Heat Treatment of Titanium and Titanium Alloys

2.3.2 Military Standards:

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

3. TECHNICAL REQUIREMENTS:

3.1 Composition: Shall conform to the following percentages by weight; hydrogen shall be determined in accordance with ASTM E146, other elements shall be determined by wet chemical methods in accordance with ASTM E120 or by spectrographic or other analytical methods approved by purchaser:

	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 Determination not required for routine acceptance.

3.1.3 Check Analysis: Composition variations shall meet the requirements of AMS 2249.

3.2 Condition: The product shall be supplied in the following condition:

3.2.1 Bars: Hot finished with or without subsequent cold reduction, duplex annealed, and descaled.

3.2.3 Forgings and Flash Welded Rings: Duplex annealed and descaled.

- 3.2.3.1 Flash welded rings shall not be supplied unless specified or permitted on purchaser's part drawing. When supplied, they shall be manufactured in accordance with AMS 7498.
- 3.2.4 Stock for Forging or Flash Welded Rings: As ordered by the forging or flash welded ring manufacturer.
- 3.3 Heat Treatment: Bars, forgings, and flash welded rings shall be duplex annealed as follows; furnace surveys and calibration of temperature controllers and recorders shall be in accordance with MIL-H-81200 or an acceptable survey and calibration program certified by the vendor as meeting the intent of MIL-H-81200:
- 3.3.1 Solution Anneal: Heat to a temperature within the range 50 - 100 F (30 - 60 C) deg below the beta transus, hold at the selected temperature within $\pm 25^{\circ}\text{F}$ ($\pm 15^{\circ}\text{C}$) for not less than 1 hr, and cool in air.
- 3.3.1.1 Beta transus temperature shall be measured with an accuracy of $\pm 10^{\circ}\text{F}$ ($\pm 5^{\circ}\text{C}$).
- 3.3.2 Anneal: Reheat to a temperature within the range 1300° - 1400°F (705° - 760°C), hold at the selected temperature within $\pm 25^{\circ}\text{F}$ ($\pm 15^{\circ}\text{C}$) for not less than 1 hr, and cool in air.
- 3.4 Properties: The product shall conform to the following requirements:
- 3.4.1 Bars, Forgings, and Flash Welded Rings: Product 6.00 in. (150.0 mm) in nominal diameter or distance between parallel sides shall have the following properties; tensile and fracture toughness properties of product over 6 in. (150.0 mm) in nominal diameter or distance between parallel sides shall be as agreed upon by purchaser and vendor:
- 3.4.1.1 Tensile Properties: Shall be as specified in Table I, determined in accordance with ASTM E8 on specimens as in 4.3.1.2 with the rate of strain maintained at 0.003 - 0.007 in./in. per min. (0.003 - 0.007 mm/mm per min.) 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 in./in. per min. (0.005 mm/mm per min.) through the yield strength and a minimum cross head speed of 0.10 in. (2.5 mm) per min. above the yield strength.
- 3.4.1.1.1 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 from which a specimen not less than 2.50 in. (62.5 mm) in length can be obtained. Tests in the longitudinal direction are not required on product tested in the transverse direction.

- 3.4.1.1.2 Longitudinal requirements in Table I 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.
- 3.4.1.2 Fracture Toughness: Specimens as in 4.3.1.3 from bars and rings 0.50 in. (12.5 mm) and over in section thickness and forgings in all section thicknesses, with prolongations if necessary, shall meet a minimum fracture toughness K_{Ic} or K_Q not lower than 70 ksi $\sqrt{\text{in}}$. (75 MPa $\sqrt{\text{m}}$). Testing shall be in accordance with ASTM E399.
- 3.4.1.2.1 Valid K_{Ic} values shall be determined in accordance with ASTM E399. Invalid plane strain fracture toughness (K_Q) values are valid if they are the result of a single invalidity and exceed the minimum K_{Ic} 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 4.6.
- 3.4.1.3 Microstructure: Shall be essentially that structure resulting from alpha-beta processing. The specific alpha plus beta microstructure shall not be cause for rejection unless standards for acceptance have been agreed upon by purchaser and vendor except that microstructure with continuous grain boundary alpha will not be acceptable.
- 3.4.1.4 Surface Contamination: Except as permitted by 3.4.1.4.1 and 3.4.1.4.2, 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 agreed upon by purchaser and vendor.
- 3.4.1.4.1 An oxygen-rich layer (See 8.1) not greater than 0.001 in. (0.025 mm) in depth will be permitted on bars other than round.
- 3.4.1.4.2 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.
- 3.4.2 Forging Stock: When a sample of stock is forged to a test coupon and heat treated as in 3.3, specimens taken from the heat treated coupon shall conform to the requirements of 3.4.1.1 and 3.4.1.2. If specimens taken from the stock after heat treatment as in 3.3. conform to the requirements of 3.4.1.1 and 3.4.1.2, the tests shall be accepted as equivalent to tests of a forged coupon.
- 3.4.3 Stock for Flash Welded Rings: A sample of stock heat treated as in 3.3 shall conform to the requirements of 3.4.1.1 and 3.4.1.2.

3.5 Quality:

3.5.1 Alloy shall be multiple melted; at least one of the melting cycles 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.

3.5.1.1 The atmosphere for nonconsumable electrode melting shall be vacuum or shall be inert gas at a pressure not higher than 250 mm of mercury.

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

3.5.2 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.

3.6 Tolerances: Bars shall conform to to all applicable requirements of AMS 2241 or MAM 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 performing all required tests. Results of such tests shall be reported to the purchaser as required by 4.5. 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 to determine conformance to the following requirements are classified as 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 (3.4.1.1), fracture toughness (3.4.1.2), microstructure (3.4.1.3), and surface contamination (3.4.1.4) of each lot of bars, forgings, and flash welded rings.

4.2.1.3 Tolerances (3.6) of each lot of bars.

4.2.2 Periodic Tests: Tests of forging stock (3.4.2) and stock for flash welded rings (3.4.3) to demonstrate ability to develop required properties are classified as periodic tests and shall be performed at a frequency selected by the vendor unless frequency of testing is specified by purchaser.

- 4.2.3 Preproduction Tests: Tests of forgings to determine conformance to all applicable technical requirements of this specification when AMS 2375 is specified are classified as preproduction tests and shall be performed prior to or on the first-article shipment of a forging to a purchaser, when a change in material, processing, or both requires reapproval as in 4.4, and when purchaser deems confirmatory testing to be required.
- 4.2.3.1 For direct U.S. Military procurement of forgings, substantiating test data and, when requested, preproduction forgings shall be submitted to the cognizant agency as directed by the procuring activity, the contracting officer, or the request for procurement.
- 4.3 Sampling: 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: At least one sample from bars and flash welded rings from each lot. The number, location, and orientation of samples from each lot of forgings shall be as agreed upon by purchaser and vendor.
- 4.3.1.2.1 Specimens 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 in. (37.5 mm) in which case 1.50 in. (37.5 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 and Preproduction Tests: As agreed upon by purchaser and vendor.
- 4.4 Approval: When specified, approval and control of forgings shall be in accordance with AMS 2375.

4.5 Reports:

- 4.5.1 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 of this specification. This report shall include the purchase order number, heat number, AMS 4931, 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.
- 4.5.2 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, AMS 4931, heat number, size, and quantity.
- 4.5.3 The vendor of finished or semi-finished parts shall furnish with each shipment, a report showing the purchase order number, AMS 4931, contractor or other direct supplier of material, part number, and quantity. When material for making parts is produced or purchased by the parts vendor, that vendor shall inspect each lot of material to determine conformance to the requirements of this specification and shall include in the report either a statement that the material conforms or copies of laboratory reports showing the results of tests to determine conformance.
- 4.6 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 and no additional testing shall be permitted. In the case of fracture toughness, a single retest is permitted for any invalidity except as noted in 3.4.1.2.1.

5. PREPARATION FOR DELIVERY:

- 5.1 Identification: The product shall be identified as follows:
- 5.1.1 Bars: In accordance with AMS 2809 as applicable to bars.
- 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.