SAE Aerospace
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# AEROSPACE MATERIAL SPECIFICATION

AMS 4928R

Issued JUL 1957
Revised JAN 2007

Superseding AMS 4928

## Titanium Alloy Bars, Wire, Forgings, Rings, and Drawn Shapes 6Al - 4V Annealed

(Composition similar to UNS R56400)

RATIONALE

AMS 4928R 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, wire, forgings, flash welded rings, drawn shapes, and stock for forging or flash welded rings.

1.2 Application

These products have been used typically for parts requiring moderate strength with a maximum service temperature in the 750 to 900 °F (399 to 510 °C) range depending on time at temperature where the product is to be used in the annealed condition, 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 form 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 canceled 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 |

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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 539 | X-Ray Emission Spectrometric Analysis of 6AI-4V Titanium Alloy |
| ASTM E 1409 | Determination of Oxygen and Nitrogen in Titanium and Titanium Alloys by the Inert Gas Fusion Technique |
| 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 | 6.75 | |
| Vanadium | 3.50 | 4.50 | |
| Iron | -- | 0.30 | |
| Oxygen | -- | 0.20 | |
| Carbon | -- | 0.08 | |
| Nitrogen | -- | 0.05 | (500 ppm) |
| Hydrogen (3.1.3); (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 wt/% (150 ppm).

3.1.2 Determination not required for routine acceptance.

3.1.3 When using ASTM E 1447 for hydrogen content, sample size may be as large as 0.35 gram.

3.1.4 Check Analysis

Composition variations shall meet the applicable requirements of AMS 2249.

3.2 Melting Practice

3.2.1 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 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 with no alloy additions permitted.

3.2.1.1 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.

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3.2.1.2 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, annealed, and descaled. Unless prohibited by purchaser, bars may be solution heat treated before annealing. The product shall be produced using standard industry practices designed strictly for the production of bar stock to the procured thickness. Cut plate shall not be supplied in lieu of bar.

3.3.2 Wire

Cold drawn, annealed, and descaled.

3.3.3 Forgings and Flash Welded Rings

Annealed and descaled. Unless prohibited by purchaser, product may be solution heat treated before annealing.

3.3.3.1 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.

3.3.4 Drawn Shapes

Drawn, annealed, and descaled. Unless prohibited by purchaser, drawn shapes may be solution heat treated before annealing.

3.3.5 Stock for Forging or Flash Welded Rings

As ordered by the forging or flash welded ring manufacturer.

3.4 Heat Treatment

Bars, wire, forgings, and flash welded rings shall be heat treated as follows; pyrometry shall be in accordance with AMS 2750.

3.4.1 Solution Heat Treatment

When solution heat treatment is used, heat to a temperature within the range 50 to 150 °F (28 to 83 °C) degrees below the beta transus, hold at the selected temperature within ±25 °F (±14 °C) for a time commensurate with section thickness and the heating equipment and procedure used, and cool at a rate equivalent to an air cool or faster.

3.4.2 Annealing

Heat to a temperature within the range 1300 to 1450 °F (704 to 788 °C), hold at the selected temperature within ±25 °F (±14 °C) for not less than 1 hour, and cool as required.

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3.5 Properties

The product shall conform to the following requirements and shall meet the requirements of 3.5.1.1 and 3.5.1.2 after being heated to any temperature up to 1250 °F (677 °C), held at heat for 20 minutes ± 3, cooled in air, and descaled:

3.5.1 Bars, Wire, Forgings, and Flash Welded Rings

Product, 6 inches (152 mm) and under in nominal diameter or distance between parallel sides, shall have the following properties:

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/s) above the yield strength.

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

| Nominal Diameter or Distance Between Parallel Sides Inches | Tensile Strength ksi (3) | Yield Strength at 0.2% Offset ksi (3) | Elongation in 2 Inches or 4D % Long. | Elongation in 2 Inches or 4D % L.T. | Elongation in 2 Inches or 4D % S.T. | Reduction of Area % Long. | Reduction of Area % L.T. | Reduction of Area % S.T. (2) |
|---|---|---|---|---|---|---|---|---|
| Up to 2.000, incl (1) | 135 | 125 | 10 | 10 | -- | 25 | 20 | -- |
| Over 2.000 to 4.000, incl | 130 | 120 | 10 | 10 | 10 | 25 | 20 | 15 |
| Over 4.000 to 6.000, incl (4) | 130 | 120 | 10 | 10 | 8 | 20 | 20 | 15 |

TABLE 2B - MINIMUM TENSILE PROPERTIES, SI UNITS

| Nominal Diameter or Distance Between Parallel Sides Millimeters | Tensile Strength MPa (3) | Yield Strength at 0.2% Offset MPa (3) | Elongation in 50.8 mm or 4D % Long. | Elongation in 50.8 mm or 4D % L.T. | Elongation in 50.8 mm or 4D % S.T. | Reduction of Area % Long. | Reduction of Area % L.T. | Reduction of Area % S.T. (2) |
|---|---|---|---|---|---|---|---|---|
| Up to 50.80, incl (1) | 931 | 862 | 10 | 10 | -- | 25 | 20 | -- |
| Over 50.80 to 101.60, incl | 896 | 827 | 10 | 10 | 10 | 25 | 20 | 15 |
| Over 101.60 to 152.40, incl (4) | 896 | 827 | 10 | 10 | 8 | 20 | 20 | 15 |

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

Note: (1) Tensile strength of 130 ksi (896 MPa) minimum and yield strength of 120 ksi (827 MPa) minimum are permitted for wire or rod for fastener applications and for flash welded rings made from extrusions up to 2.000 inches (50.80 mm), inclusive, in distance between parallel sides.
(2) Short-transverse reduction of area is waived for flash welded rings made from extrusions.
(3) Tensile and yield strength requirements apply in both the longitudinal and transverse directions.
(4) See 8.3.

3.5.1.1.1 Longitudinal requirements in Table 2 apply to specimens from bars and wire 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.

3.5.1.1.2 Transverse requirements in Table 2 apply only to product from which a tensile specimen not less than 2.50 inches (63.5 mm) in length can be obtained.

3.5.1.1.3 Yield strength and reduction of area requirements do not apply to wire and drawn shapes with maximum section thickness under 0.125 inch (3.18 mm) in nominal diameter.

3.5.1.2 Microstructure

Shall be that structure resulting from processing within the alpha-beta phase field. Microstructure shall conform to 3.5.1.2.1 or 3.5.1.2.2, or 3.5.1.2.3.

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

3.5.1.2.2 Essentially complete field of equiaxed and/or elongated alpha with no continuous network of alpha at prior beta grain boundaries.

3.5.1.2.3 Partially broken and distorted grain boundary alpha with plate-like alpha.

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

3.5.1.3 Surface Contamination

Except as permitted by 3.5.1.3.1 and 3.5.1.3.2, the product shall be free of any oxygen-rich layer (See 8.2), such as alpha case, or other surface contamination, determined by microscopic examination at not lower than 100X magnification or other method acceptable to purchaser.

3.5.1.3.1 An oxygen-rich layer not greater than 0.001 inch (0.025 mm) in depth will be permitted on bars other than round, and drawn shapes.

3.5.1.3.2 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. If specimens taken from the stock after heat treatment as in 3.4 conform to the requirements of 3.5.1.1, the tests shall be accepted as equivalent to tests of a forged coupon.

3.5.3 Stock for Flash Welded Rings

A sample of stock heat treated as in 3.4 shall conform to the requirements of 3.5.1.1.

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.

3.6.1 Grain flow of die forgings, except in areas which contain flash-line end grain, shall follow the general contour of the forgings showing no evidence of reentrant grain flow.

3.7 Tolerances

Bars and wire 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 test 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.

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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 and hydrogen content of each lot.

4.2.1.2 Tensile properties (3.5.1.1), microstructure (3.5.1.2), and surface contamination (3.5.1.3) of each lot of bars, wire, forgings, flash welded rings, and drawn shapes, as received.

4.2.1.3 Tolerances (3.7) of bars and wire.

4.2.2 Periodic Tests

The following requirements are periodic tests and shall be performed at a frequency selected by the vendor unless frequency of testing is specified by purchaser:

4.2.2.1 Tensile properties (3.5.1.1) of bars, wire, forgings, flash welded rings, and drawn shapes after reheating as in 3.5.

4.2.2.2 Ability of forging stock (3.5.2) and stock for flash welded rings (3.5.3) to develop required properties.

4.2.2.3 Grain flow of die forgings (3.6.1).

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 solution heat treated and 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, wire, flash welded rings, and drawn shapes from each lot. The number, location, and orientation of samples from each lot of forgings shall be as agreed upon by purchaser and vendor.

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

4.3.1.3 Microstructure and Surface Contamination

At least one sample from each lot.

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4.4 Reports

4.4.1 Raw Material

The vendor shall provide a copy of the original material manufacturer's report (material certification), including: producer name, product form, mill produced size, and country where the metal was melted (i.e., final melt in the case of metal processed by multiple melting operations). The vendor of bars, wire, forgings, flash welded rings and drawn shapes shall furnish with each shipment a report showing the results of tests for composition of each heat and for the hydrogen content and tensile properties of each lot, and stating that the product conforms to the other technical requirements. This report shall include the purchase order number, lot number, AMS 4928R, size, specific heat treatment used, and quantity. If forgings are supplied, the part number and the size of stock used to make the forgings shall also be included. 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. This report shall include the purchase order number, heat number, AMS 4928R, size, and quantity.

4.4.2 Fabricated Parts

A copy of the original manufacturer's report (material certification) shall be provided by the vendor to the purchaser when the purchase order specifies AMS 4928R.

4.5 Resampling and Retesting

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. Results of all tests shall be reported.

5. PREPARATION FOR DELIVERY

5.1 Identification

Shall be as follows:

5.1.1 Bars and Wire

In accordance with AMS 2809.

5.1.2 Forgings

In accordance with AMS 2808.

5.1.3 Flash Welded Rings, Stock for Forging or Flash Welded Rings and Drawn Shapes

As agreed upon by purchaser and vendor.

5.2 Packaging

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.

6. ACKNOWLEDGMENT

A vendor shall mention this specification number and its revision letter in all quotations and when acknowledging purchase orders.

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7. REJECTIONS

Product not conforming to this specification, or to modifications authorized by purchaser, will be subject to rejection.

8. NOTES

8.1 A change bar (|) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this specification. An (R) symbol to the left of the document title indicates a complete revision of the specification, including technical revisions. Change bars and (R) are not used in original publications, nor in specifications that contain editorial changes only.

8.2 An oxygen-rich layer, such as alpha case, is hard and brittle and results in marked lowering of fatigue properties.

8.3 "A" values given in MMPDS are lower than specification values for product over 4 to 6 inches (102 to 152 mm), inclusive, in section thickness.

8.4 “Terminology for Titanium Microstructures” is presented in AS1814.

8.5 Terms used in AMS are clarified in ARP1917.

8.6 Dimensions and properties in inch/pound units and the Fahrenheit temperatures are primary; dimensions and properties in SI units and the Celsius temperatures are shown as the approximate equivalents of the primary units and are presented only for information.

8.7 Purchase documents should specify not less than the following:

AMS 4928R
Product form and size or part number of product desired
Quantity of product desired.

8.8 Similar Specifications

AMS-T-9047 and MIL-T-9047 are listed for information only and shall not be construed as an acceptable alternate unless all requirements of this AMS are met.

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