



# AEROSPACE MATERIAL SPECIFICATION

**AMS4928™****REV. W**Issued 1957-07  
Revised 2017-12

Superseding AMS4928V

Titanium Alloy Bars, Wire, Forgings, Rings, and Drawn Shapes  
6Al - 4V Annealed  
(Composition similar to UNS R56400)

## RATIONALE

AMS4928W results from an update of this specification that revises composition testing analytical methods (3.1), increases upper size limit to 10 inches (3.5.1), changes minimum magnification for surface contamination (3.5.1.3) and revises reporting (4.4) and identification (5.1).

### 1. SCOPE

#### 1.1 Form

This specification covers a titanium alloy in the form of bars, wire, forgings, flash welded rings, drawn shapes up through 10.000 inches (254.00 mm) inclusive in diameter or least distance between parallel sides and stock of any size 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 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](http://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
AMS2750	Pyrometry
AMS2808	Identification Forgings

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AMS2809	Identification Titanium and Titanium Alloy Wrought Products
AMS7498	Rings, Flash Welded Titanium and Titanium Alloys
ARP1917	Clarification of Terms Used in Aerospace Metals Specifications
AS1814	Terminology for Titanium Microstructures
AS6279	Standard Practice for 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](http://www.astm.org).

ASTM E8/E8M	Tension Testing 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
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
ASTM E2994	Analysis of Titanium and Titanium Alloys by Spark Atomic Emission Spectrometry and Glow Discharge 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, ASTM E2371 or ASTM E2994. 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 (3.1.1)	--	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 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 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, annealed, and descaled. Unless prohibited by purchaser, bars may be solution heat treated before annealing. A machined or ground surface is permitted unless prohibited by the purchaser. 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 be cut from plate.

#### 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 AMS7498.

#### 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, drawn shapes and flash welded rings shall be heat treated as follows; pyrometry shall be in accordance with AMS2750.

#### 3.4.1 Solution Heat Treatment

Except as specified in 3.4.3, when solution heat treatment is used, heat to a temperature within the range 50 to 150 °F (28 to 83 °C) below the beta transus, hold at the selected temperature within  $\pm 25$  °F ( $\pm 14$  °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

Except as specified in 3.4.3, heat to a temperature within the range 1300 to 1450 °F (704 to 788 °C), hold at the selected temperature within  $\pm 25$  °F ( $\pm 14$  °C) for not less than 1 hour, and cool as required.

### 3.4.3 Continuous Heat Treating

Wire 0.125 inch (3.18 mm) and under in diameter may be continuously heat treated provided that process parameters (e.g., furnace temperature set points, heat input, travel rate, etc.) for continuous heat treating lines shall be established by the material producer and validated by testing of product to requirements of 3.5.

## 3.5 Properties

The product shall conform to the following requirements and shall also meet the requirements of 3.5.1.1 after being heated to any temperature up to 1250 °F (677 °C) (see 4.2.2), held at heat for 20 minutes  $\pm$  3 minutes, cooled in air, and descaled:

### 3.5.1 Bars, Wire, Forgings, and Flash Welded Rings

Product, 10.000 inches (254.00 mm) and under in nominal diameter or least 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 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  $\pm 0.002$  inch/inch/minute (0.002 mm/mm/minute) through the 0.2% offset yield strain.

**Table 2**

**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 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 (3)	130	120	10	10	8	20	20	15
Over 6.000 to 10.000, incl	130	119	10	10	8	20	20	15

**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 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 (3)	896	827	10	10	8	20	20	15
Over 152.40 to 254.00, incl	896	820	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. See 8.3.

- 3.5.1.1.1 Tensile and yield strength requirements apply in the longitudinal and the long and short transverse directions. Transverse requirements in Table 2 apply only to product that a tensile specimen not less than 2.50 inches (63.5 mm) in length can be obtained.
- 3.5.1.1.2 Tests in transverse directions are not required on product tested in the longitudinal direction unless specified by purchase order.
- 3.5.1.1.3 Specimens for the longitudinal requirements in Table 2 for bars, wire, and forgings shall be taken with the axis of the specimen approximately within 15° of parallel to the grain flow and for flash welded rings shall be taken in the circumferential direction.
- 3.5.1.1.4 Yield strength and reduction of area requirements do not apply to wire and drawn shapes with maximum section thickness under 0.125 inches (3.18 mm) in nominal diameter.
- 3.5.1.1.5 Mechanical property requirements for product outside the range covered by 1.1 shall be agreed upon between purchaser and producer.

#### 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.

- 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, by examination of a metallographic cross section at 400X minimum magnification or by other method agreed upon by purchaser and producer.

- 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 AMS2241.

3.8 Production, distribution, and procurement of metal stock shall comply with AS6279.

## 4. QUALITY ASSURANCE PROVISIONS

### 4.1 Responsibility for Inspection

The producer of the product shall supply all samples for producer'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.

### 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 producer 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 for each required testing direction 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 producer.

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.

### 4.4 Reports

4.4.1 The producer shall provide a report showing the producer identity, country where the metal was melted (e.g., final melt in the case of metal processed by multiple melting operations), the results of tests for composition of each heat and for the hydrogen content and tensile properties of each lot, and state that the product conforms to the other technical requirements. This report shall include the purchase order number, lot number, AMS4928W, product form and mill produced size (and/or part number, if applicable), 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 producer 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, AMS4928W, size, and quantity.

4.4.2 Report the nominal metallurgically worked cross sectional size and the cut size, if different (see 3.3.1).

4.4.3 When material produced to this specification is beyond the sizes allowed in the scope or tables, or other exceptions are taken to the technical requirements listed in Section 3, (see 5.1) the report shall contain a statement "This material is certified as AMS4928W(EXC) because of the following exceptions:" and the specific exceptions shall be listed.

### 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

#### 5.1.1 Bars and Wire

In accordance with AMS2809. When technical exceptions are taken (see 4.4.3), the material shall be identified with AMS4928W(EXC).

#### 5.1.2 Forgings

In accordance with AMS2808.

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

As agreed upon by purchaser and producer.

### 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 producer shall include this specification number and its revision letter in all quotations and when acknowledging purchase orders.

## 7. REJECTIONS

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

## 8. NOTES

### 8.1 Revision Indicator

A change bar (I) 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 document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents 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:

AMS4928W

Product form and size (and/or part number, if applicable) of product desired

Quantity of product desired

Property and acceptance requirements from the cognizant engineering organization applicable to sizes outside the size range listed in 1.1

### 8.8 Similar Specifications

AMS-T-9047 and MIL-T-9047 are listed for information only.

PREPARED BY AMS COMMITTEE "G"