AEROSPACE MATERIAL SPECIFICATION

AMS4943™	REV. L

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Superseding AMS4943K

Titanium Alloy, Hydraulic, Seamless Tubing
3.0Al - 2.5V
Annealed

(Composition similar to UNS R56320)

RATIONALE

AMS4943L results from a Five-Year Review and update of this specification that adds composition analytical methods (3.1), prohibits unauthorized exceptions (3.7), corrects reference (4.2.3), and revises reporting (4.5.2) and identification (5.1).

1. SCOPE

1.1 Form

This specification covers a titanium alloy in the form of seamless tubing.

1.2 Application

This tubing has been used typically for parts, such as hydraulic lines, requiring strength and oxidation resistance up to 600 °F (316 °C) and weldability, 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.

AMS2244	Tolerances, Titanium and Titanium Alloy Tubing
AMS2249	Chemical Check Analysis Limits, Titanium and Titanium Alloys
AMS2368	Sampling and Testing of Wrought Titanium Raw Material Except Forgings and Forging Stock
AMS2634	Ultrasonic Inspection Thin Wall Metal Tubing

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http://standards.sae.org/AMS4943L

AMS2750	Pyrometry
AMS2809	Identification Titanium and Titanium Alloy Wrought Products
ARP1917	Clarification of Terms Used in Aerospace Metals Specifications
AS1814	Terminology for Titanium Microstructures

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 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 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 Atomic Emission Spectrometry
ASTM E2994	Analysis of Titanium and Titanium Alloys by Spark Atomic Emission Spectrometry and Glow Discharge Atomic Emission Spectrometry

2.3 ASME Publications

Available from ASME, P.O. Box 2900, 22 Law Drive, Fairfield, NJ 07007-2900, Tel: 800-843-2763 (U.S./Canada), 001-800-843-2763 (Mexico), 973-882-1170 (outside North America), www.asme.org.

ASME B46.1	Surface Texture (Surface Roughness, Waviness, and Lay)

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	2.50	3.50	
Vanadium	2.00	3.00	
Iron	--	0.30	
Oxygen	--	0.12	
Carbon	--	0.05	
Nitrogen	--	0.020	(200 ppm)
Hydrogen	--	0.005	(50 ppm)
Yttrium (3.1.1)	--	0.005	(50 ppm)
Other Elements, each (3.1.1)	--	0.10	
Other Elements, total (3.1.1)	--	0.40	
Titanium	remainder		

3.1.1 Determination not required for routine acceptance.

3.1.2 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

Cold reduced, annealed by heating to a temperature within the range 1100 to 1450 °F (593 to 788 °C), holding at the selected temperature within ±25 °F (±14 °C) for not less than 30 minutes, cooling at a rate equivalent to an air cool or slower, and descaled. Pyrometry shall be in accordance with AMS2750.

3.3.1 Furnaces shall meet the requirements of AMS2750. Furnaces shall be a minimum Class 5 (±25 °F/±14 °C), with a minimum of Type D instrumentation.

3.3.2 Heat treatment operations shall be performed under vacuum or inert gas.

3.4 Properties

Tubing shall conform to the following requirements:

3.4.1 Tensile Properties

Shall be as shown in Table 2, determined in accordance with ASTM E8/E8M with the rate of strain set at 0.005 in/in/min (0.005 mm/mm/min) and maintained within a tolerance of ±0.002 in/in/min (0.002 mm/mm/min) through the 0.2% offset yield strain.

Table 2 - Minimum tensile properties

Property	Value
Tensile Strength	90 ksi (621 MPa)
Yield Strength at 0.2% Offset	75 ksi (517 MPa)
Elongation in 2 Inches (50.8 mm)	15%

3.4.2 Flarability

Specimens as in 4.3.4.1 shall withstand flaring at room temperature, without formation of cracks or other visible defects, by being forced axially, with steady pressure, over a hardened and polished tapered steel pin having a 74-degree included angle to produce a flare having a permanent expanded OD not less than 1.30 times the original nominal OD.

3.4.3 Pressure Testing

Tubing shall show no bulges, leaks, pin holes, cracks, or other defects when subjected to an internal hydrostatic pressure (P) sufficient to cause a tensile stress of 75 ksi (517 MPa) in the tubing wall, except that a diametric permanent set of 0.002 in/in (0.002 mm/mm) of diameter is acceptable. The hydrostatic pressure (P) shall be determined using Equation 1.

$$P = S\,\frac{D^2 - d^2}{D^2 + d^2} \qquad \text{(Eq. 1)}$$

where:

P = test pressure in ksi (MPa)

S = 75 ksi (517 MPa)

D = nominal OD

d = nominal ID

3.4.4 Bending

Tubing shall not develop cracks, tears, breaks, or other flaws when bent at ambient temperature 180 degrees around a suitable bend die having a centerline radius equal to three times the nominal OD of the tubing. A solid rod or ball-type retractable mandrel inserted to the tangent of the bend shall be used to support the inside of the tube during bending.

3.4.5 Flattening

Specimens as in 4.3.5 shall show no cracks, tears, breaks, opened die marks, or opened polishing marks when a half-section of a tube is flattened between parallel plates until the distance between plates is essentially equal to the wall thickness of the tube. The flattened sample shall be examined under a binocular microscope at 5 to 10X magnification.

3.4.5.1 As an alternate flattening test method, the half-tube sample may be placed between mandrels and pressed

together to produce a flat surface approximately 3/8 inch (9.5 mm) wide on the tubing ID. The mandrel or mandrels shall be positioned so that the width of the flattened area will be parallel to the length of the half-section of tubing.

3.4.6 Microstructure

Shall be that structure resulting from processing within the alpha-beta phase field. Microstructure shall conform to 3.4.6.1 or 3.4.6.2.

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

3.4.6.2 Essentially complete field of equiaxed and/or elongated alpha with or without intergranular beta and with no

3.4.7 The tubing shall be free of any oxygen-rich layer, such as alpha case (see 8.2), or other surface contamination, determined by microscopic examination at not lower than 400X magnification or by other method acceptable to purchaser and producer.

3.5 Quality

Tubing, as received by purchaser, shall be uniform in quality and condition and shall have a finish conforming to the best practice for high quality aircraft tubing. It shall be smooth and free from heavy scale or oxide, burrs, seams, tears, cracks, grooves, laminations, slivers, pits, and other imperfections detrimental to usage of the tubing. Surface imperfections, such as handling marks, straightening marks, light mandrel and die marks, shallow pits, and scale pattern will not be considered injurious if the imperfections are removable within the tolerances specified for wall thickness but removal of such imperfections is not required.

3.5.1 Each tube shall be ultrasonically inspected in accordance with AMS2634, Class AA, for ID, OD, and subsurface imperfections of all types and orientation (longitudinal and transverse).

3.5.2 Surface Condition

3.5.2.1 OD Surface

Shall show a uniformly acid-pickled surface finish; not less than 0.001 inch (0.025 mm) shall have been chemically removed from the wall thickness as a finishing operation. Soft belt polishing prior to the pickling operation is permissible; traces of the polishing marks may remain after the pickling operation. Centerless grinding or other mechanical operations are not permitted.

3.5.2.2 ID Surface

Shall show a uniform matte finish, produced by abrasive blasting with grit not larger than 100 mesh (150 µm) followed by forced-flow acid pickling to remove not less than 0.0005 inch (0.013 mm) from the wall thickness.

3.5.2.3 Surface Texture

Shall be not greater than 63 microinches (1.6 microinches) Ra on the ID and be not greater than 32 µin (0.8 µm) Ra on the OD, determined in accordance with ASME B46.1.

3.5.3 Surface Cleanliness

The ID and OD surfaces of the tubing shall be free from grease and other foreign matter. Metallic flakes or particles shall not be collected by a clean, white cloth drawn through the bore of a sample tube. Discoloration of the cloth, without the presence of metallic flakes or particles, is acceptable.

3.6 Tolerances

Shall conform to all applicable requirements of AMS2244 for special tolerances.

3.7 Exceptions

Any exceptions shall be authorized by purchaser and reported as in 4.5.2.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for Inspection

The producer of tubing shall supply all samples for producer'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 tubing conforms to specified requirements.

4.2 Classification of Tests

4.2.1 Acceptance Tests

All technical requirements, except pressure testing (3.4.3), are acceptance tests and shall be performed on each heat or lot as applicable.

4.2.2 Periodic Tests

Pressure testing (3.4.3) is a periodic test and shall be performed at a frequency selected by the producer unless frequency of testing is specified by purchaser.

4.2.3 Preproduction Tests

All technical requirements are preproduction tests and shall be performed prior to or on the initial shipment of tubing to a purchaser, when a change in material and/or processing requires reapproval as in 4.4.1, and when purchaser deems confirmatory testing to be required.

4.3 Sampling and Testing

Shall be in accordance AMS2368 and the following; a lot shall be all tubing of the same nominal size from the same ingot, same processing and finishing operations, and annealed in the same furnace charge:

4.3.1 Composition

One sample from each heat except that for hydrogen determinations, one sample from each lot obtained after thermal and chemical processing is completed. An ingot analysis obtained from the alloy producer may be utilized to substantiate heat requirements.

4.3.2 Tensile Properties

One sample from each 1000 feet (305 m) or three samples from each lot, whichever is greater.

4.3.3 Microstructure

One sample from each lot.

4.3.4 Pressure, Bend, and Flarability Tests

Three samples from each lot:

4.3.4.1 Specimens for the flarability test (3.4.2) shall be full tubes or sections cut from a tube. The end of the specimen to be flared shall be cut square, with the cut end smooth and free from burrs, but not rounded.

4.3.5 Flattening Test

One sample from each 135 feet (41 m) of tubing or 10 samples from each lot, whichever is less. Each specimen shall be at least 2 inches (51 mm) long, cut in half, with the cuts being parallel to the axis of the tube.

4.3.6 Ultrasonic Tests

Each tube.

4.3.7 Surface Condition and Tolerances

Each tube, except that ID surface inspection need only be made on each sample selected for the flattening test.

4.4 Approval

Sample tubing or process sheets showing the process control factors for producing the tubing shall be approved by the purchaser before tubing for production use is supplied, unless such approval is waived by purchaser.

4.4.1 Producer shall establish parameters for the process control factors which will produce tubing meeting the technical requirements of this specification. If necessary to make any change in parameters for the process control factors, producer shall submit, for reapproval, revised process sheets and, when requested, sample tubing. Tubing incorporating the revised operations shall not be shipped prior to receipt of reapproval.

4.4.1.1 Control factors for producing tubing include, but are not limited to, the following:

Acceptance criteria for tube hollows
Conditioning practice for tube hollows
Cold working procedures
Annealing procedures
Tube ID and OD finishing operations
Final inspection procedures

4.4.1.2 Any of the process control factors for which parameters are considered proprietary by the producer may be assigned a code designation. Each variation in such parameters shall be assigned a modified code designation.

4.5 Reports

4.5.1 The producer shall furnish with each shipment a report showing producer identity, country where the metal was melted (i.e., final melt in the case of metal processed by multiple melting operations), results of tests for composition of each heat and for the hydrogen content, tensile properties, pressure test, bend test, and flattening requirements of each lot and stating that the tubing conforms to the other technical requirements. This report shall include the purchase order number, heat and lot numbers, AMS4943L, size, and quantity.

4.5.2 When material produced to this specification is beyond the sizes allowed in the scope or tables, or exceptions authorized by purchaser are taken to the technical requirements listed in Section 3, the report shall contain a statement "This material is certified as AMS4943L(EXC) because of the following exceptions:" and the specific exceptions shall be listed (see 5.1).

4.6 Resampling and Retesting

If any specimen used in the above tests fails to meet specified requirements, disposition of the tubing may be based on the results of testing three additional specimens, from tubes not tested in the original sampling, for each original nonconforming specimen. Failure of any retest specimen to meet specified requirements shall be cause for rejection of the tubing represented. Results of all tests shall be reported.

5. PREPARATION FOR DELIVERY

5.1 Identification

In accordance with AMS2809. When technical exceptions are taken (see 4.5.2), the material shall be identified with AMS4943L(EXC).

5.2 Packaging

Tubing 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 tubing to ensure carrier acceptance and safe delivery.

5.2.1 A lot of tubing may be packaged in small quantities and delivered under the basic lot approval provided lot identification is maintained.

6. ACKNOWLEDGMENT

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

7. REJECTIONS

Tubing 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 (l) 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 Terms used in AMS are clarified in ARP1917.

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

8.4 Terminology relating to titanium microstructures is presented in AS1814.

8.5 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.

8.6 It is the Purchaser's obligation to ensure that product they procure or resell as AMS4943L has any exceptions approved by their subsequent purchaser.

8.7 Purchase documents should specify not less than the following:

AMS4943L
Size of tubing desired
Quantity of tubing desired

8.8 Unless otherwise specified, the material producer shall work to the revision of this specification (AMS4943) in effect on the date of order placement. Unless otherwise specified, material manufactured and certified to the immediately previous revision of this specification (AMS4943) may be procured and used until inventory is depleted.