SAE Aerospace
An SAE International Group

AEROSPACE MATERIAL SPECIFICATION

SAE AMS4944 REV. H

Issued 1974-06
Revised 2010-10

Superseding AMS4944G

Titanium Alloy Tubing, Seamless, Hydraulic
3.0Al - 2.5V
Cold Worked, Stress Relieved

(Composition similar to UNS R56320)

RATIONALE

AMS4944H 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 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 724-776-4970 (outside USA), www.sae.org.

AMS2244	Tolerances, Titanium and Titanium Alloy Tubing
AMS2249	Chemical Check Analysis Limits, Titanium and Titanium Alloys
AMS2634	Ultrasonic Inspection, Thin Wall Metal Tubing
AMS2809	Identification, Titanium and Titanium Alloy Wrought Products
AS33611	Tube Bend Radii

SAE Technical Standards Board Rules provide that: "This report is published by SAE to advance the state of technical and engineering sciences. The use of this report is entirely voluntary, and its applicability and suitability for any particular use, including any patent infringement arising therefrom, is the sole responsibility of the user."
SAE reviews each technical report at least every five years at which time it may be reaffirmed, revised, or cancelled. SAE invites your written comments and suggestions.
Copyright © 2010 SAE International
All rights reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior written permission of SAE.

TO PLACE A DOCUMENT ORDER:
Tel: 877-606-7323 (inside USA and Canada)
Tel: +1 724-776-4970 (outside USA)
Fax: 724-776-0790
Email: CustomerService@sae.org
SAE WEB ADDRESS: http://www.sae.org

SAE values your input. To provide feedback on this Technical Report, please visit http://www.sae.org/technical/standards/AMS4944H

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 / E 8M	Tension Testing of Metallic Materials
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

2.3 ASME Publications

Available from American Society of Mechanical Engineers, 22 Law Drive, P.O. Box 2900, Fairfield, NJ 07007-2900, Tel: 973-882-1170, www.asme.org.

ASME B46.1	Surface Texture

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 2371. 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 (3.1.3)	--	0.015 (150 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.

3.1.3 For hydrogen analysis, conducted in accordance with ASTM E 1447, sample size may be as large as 0.35 gram.

3.2 Melting Practice

Alloy shall be multiple melted; the final melting cycle shall be under vacuum. The first melt shall be made using vacuum consumable electrode, nonconsumable electrode, electron beam cold hearth, or plasma arc cold hearth melting practice(s). The final melting cycle shall be made using vacuum arc remelting (VAR) practice with no alloy additions permitted.

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 worked and stress relieved by heating to a temperature not lower than 700 °F (371 °C) and holding at heat for not

less than 30 minutes. Tubing that is rotary straightened after final reduction shall be stress relieved at a minimum temperature of 700 °F for not less than 2 hours after straightening. Pyrometry shall be in accordance with AMS2750.

3.3.1 Furnaces shall meet the requirements of instrumentation type D, C, B or A (AMS2750) for Type A furnaces. Uniformity shall be between ±25 °F (±14 °C) or less, with a readability requirement of ±2 °F (±1 °C).

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 E 8 / E 8M, with the rate of strain set at 0.005 inch/inch/minute (0.005 mm/mm/minute) and maintained within a tolerance of ±0.002 inch/inch/minute (0.002 mm/mm/minute) through the 0.2% offset yield strain.

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

Nominal Wall Thickness Inch	Tensile Strength ksi	Yield Strength at 0.2% Offset ksi	Elongation in 2 Inches or 4D %
Up to 0.016, incl	125	105	8
Over 0.016	125	105	10

TABLE 2B - MINIMUM TENSILE PROPERTIES, SI UNITS

Nominal Wall Thickness Millimeters	Tensile Strength MPa	Yield Strength at 0.2% Offset MPa	Elongation in 50.8 mm or 4D %
Up to 0.41, incl	862	724	8
Over 0.41	862	724	10

3.4.2 Flarability

Specimens as in 4.3.3 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 1.20 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 105 ksi (724 MPa) in the tubing wall, except that a diametric permanent set of 0.002 inch per inch (0.002 mm/mm) of diameter is acceptable. The hydrostatic pressure (P) shall be determined using Equation 1:

$$P = S \frac{D^2 - d^2}{\quad}$$

wnere:

P = Test pressure in ksi (MPa)
S = 105 ksi (724 MPa)
D = Nominal OD
d = Nominal ID

3.4.4 Bending

Tubing shall not develop cracks, tears, breaks, or other flaws when bent 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, or an appropriate tube filler, shall be used to support the inside of the tube during bending to restrict flattening to a value that does not exceed 3% of the nominal OD of the tube. Flattening shall be measured in accordance with AS33611.

3.4.5 Flattening

The inside and outside surfaces of tubing shall show no cracks, tears, breaks, opened die marks, or opened polishing marks when a full section of the tube is flattened between parallel plates under a load applied gradually and perpendicularly to the longitudinal axis until the distance between the plates is not greater than shown in Table 3. After

examination of the outside surfaces, the samples shall be split longitudinally and the inside surfaces examined under 5 to 10X magnification.

TABLE 3 - FLATTENING PARAMETERS

Outside Diameter To Wall Thickness Ratio OD/t	Distance Between Plates (t = Wall Thickness)
Up to 12, incl	Not Required
Over 12 to 16, incl	12t
Over 16 to 30, incl	15t
Over 30 to 50, incl	17t

3.4.5.1 As an alternate flattening test, a half-tube sample shall be pressed to produce a flat surface approximately 3/8 inch (9.5 mm) wide on the tubing ID.

3.4.6 Microstructure

Shall be predominantly an elongated wrought structure but some areas of partially transformed beta structure are acceptable. Tubing shall be free of any oxygen-rich layer, such as alpha case, or other surface contamination, determined by microscopic examination at not lower than 400X magnification or by other method agreed upon by purchaser and vendor (See 8.2).

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, clean, and free from scale or oxide, burrs, seams, tears, grooves, laminations, slivers, pits, and other imperfections detrimental to usage of the tubing. Surface imperfections, such as handling marks or straightening marks, 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 Roughness

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

3.5.2.4 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 length of the bore of a test sample. Discoloration of the cloth, without the presence of flakes or particles, is acceptable

3.6 Tolerances

Shall conform to the following:

3.6.1 Outer Diameter

Shall be as shown in Table 4; tolerances shown include ovality.

TABLE 4A - OD TOLERANCES, INCH/POUND UNITS

Nominal OD Inches	Tolerance Inch plus	Tolerance Inch minus
Over 0.093 to 0.188, incl	0.002	0.000
Over 0.188 to 0.500, incl	0.003	0.000
Over 0.500 to 1.000, incl	0.004	0.000
Over 1.000 to 1.500, incl	0.004	0.001
Over 1.500 to 2.000, incl	0.005	0.001

TABLE 4B - OD TOLERANCES, SI UNITS

Nominal OD Millimeters	Tolerance Millimeter plus	Tolerance Millimeter minus
Over 2.36 to 4.78, incl	0.05	0.00
Over 4.78 to 12.70, incl	0.08	0.00
Over 12.70 to 25.40, incl	0.10	0.00
Over 25.40 to 38.10, incl	0.10	0.02
Over 38.10 to 50.80, incl	0.13	0.02

3.6.2 Wall Thickness

All tubing 1.500 inches (38.10 mm) and under in nominal OD shall not vary more than +10%, -5% from nominal; tubing over 1.500 inches (38.10 mm) in nominal OD shall not vary more than ±10%.

3.6.3 Length and Straightness

Shall conform to AMS2244.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for Inspection

The vendor of tubing shall supply all samples for vendor'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 vendor 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 4.4.2, and when purchaser deems confirmatory testing to be required.

4.3 Sampling and Testing

Shall be in accordance with the following; a lot shall be all tubing of the same nominal size from the same heat, same processing, and finishing operations, and stress relieved 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 for each 1000 feet (305 mm) or 3 samples from each lot, whichever is greater.

4.3.3 Flarability

One sample per tube for lot sizes consisting of four tubes or less and four samples for lot sizes consisting of 5 to 39 tubes. For lot sizes of 40 or more tubes, one test from one end of 10% of the tubes.

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

4.3.4 Pressure Test

As agreed upon by purchaser and vendor.

4.3.5 Bending

Two samples from each lot.

4.3.6 Flattening

One sample for each 135 feet (41 m) of tubing or 10 samples from each lot, whichever is less. Each specimen shall be not less than 2 inches (51 mm) long, cut in half, with the cuts being parallel to the axis of the tube.

4.3.7 Microstructure

One sample from each lot.

4.3.8 Surface Condition

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

4.3.9 Ultrasonic Inspection and Tolerances

Each tube.

4.4 Approval

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

4.4.2 Vendor shall establish parameters for the process control factors that will produce tubing meeting the technical requirements. If necessary to make any change in parameters for the process control factors, vendor 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.

4.4.2.1 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
Intermediate tube annealing, conditioning, and inspection procedures
Tube ID and OD finishing operations
Final inspection procedures.

4.4.2.1.1 Any of the above process control factors that parameters are considered proprietary by the vendor may be assigned a code designation. Each variation in such parameters shall be assigned a modified code designation.

4.5 Reports

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 tubing shall furnish with each shipment a report showing the results of tests for composition of each heat and for the hydrogen content, tensile properties, flarability, bending, flattening, and microstructure requirements of each lot, and stating that the tubing conforms to the other technical requirements. This report shall include the purchase order number, lot number, AMS4944H, size, and quantity.

4.6 Resampling and Retesting

If any specimen used in the above tests fails to meet the 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 the 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.

5.2 Packaging

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.

5.2.2 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.

6. ACKNOWLEDGMENT

A vendor 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 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 Acceptance standards for microstructure and surface contamination (3.4.6) may be established by agreement between purchaser and vendor.

8.3 Terms used in AMS are clarified in ARP1917.

8.4 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.

8.5 Purchase documents should specify not less than the following:

AMS4944H
Size of tubing desired
Quantity of tubing desired.