AEROSPACE MATERIAL SPECIFICATION

AMS4941™	REV. H

Issued 1956-07
Reaffirmed 1994-04
Revised 2023-08

Superseding AMS4941G

Titanium Tubing, Welded
40 ksi (276 MPa) Yield Strength
(Composition similar to UNS R50400)

RATIONALE

AMS4941H results from a Five-Year Review and update of the specification. Changes have been made to add ASTM E539 analytical method (see 2.2 and 3.1), update wording prohibiting unauthorized exceptions (see 3.10 and 8.4), Tensile Properties (see Table 2), thickness of tubing in the area away from the weld (see 3.9.2.1), and Applicable Documents (see Section 2), relocate Definitions (see 2.4), and allow use of immediate prior specification revision (see 8.5).

1. SCOPE

1.1 Form

This specification covers one grade of commercially pure titanium in the form of welded tubing.

1.2 Application

This tubing has been used typically for parts, such as low-pressure fluid-conducting lines and conduits, requiring strength up to 400 °F (204 °C) and oxidation resistance up to 600 °F (316 °C), 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.

AMS2242 Tolerances, Corrosion and Heat Resistant Steel, Iron Alloy, Titanium and Titanium Alloy Sheet, Strip, and Plate

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

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**

For more information on this standard, visit
https://www.sae.org/standards/content/AMS4941H/

AMS2750 Pyrometry

AMS2809 Identification, Titanium and Titanium Alloy Wrought Products

AMS4902 Titanium Sheet, Strip, and Plate, Commercially Pure, Annealed 40.0 ksi (276 MPa) Yield Strength

AMS4951 Titanium Welding Wire, Commercially Pure, Environment Controlled Packaging

AS7766 Terms Used in Aerospace Metals Specifications

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 Wavelength Dispersive 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 Reactive Metals and Reactive Metal Alloys by Inert Gas Fusion with Detection by Thermal Conductivity or Infrared Spectrometry

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 (Performance-Based Test Methodology)

ASTM E2994 Analysis of Titanium and Titanium Alloys by Spark Atomic Emission Spectrometry and Glow Discharge Atomic Emission Spectrometry (Performance-Based Method)

2.3 AWS Publications

Available from American Welding Society, 8669 NW 36 Street, #130, Miami, FL 33166-6672, Tel: 1-800-443-9353 or 305-443-9353, www.aws.org.

AWS A5.16 Specification for Titanium and Titanium Alloy Welding Electrodes and Rods

AWS D17.1 Specification for Fusion Welding for Aerospace Applications

2.4 Definitions

Terms used in AMS are defined in AS7766.

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
Carbon	--	0.08
Oxygen	--	0.20
Iron	--	0.30
Nitrogen	--	0.05 (500 ppm)
Hydrogen	--	0.015 (150 ppm)
Other Elements, each (3.1.1)	--	0.10
Other Elements, total (3.1.1)	--	0.30
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

3.2.1 Alloy shall be produced by electron beam cold hearth or plasma arc cold hearth melting, or shall be multiple melted. When 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. Subsequent melt or melts shall be made using vacuum arc remelting (VAR) practice. Alloy additions are not permitted in the final melt cycle.

3.2.1.1 The atmosphere for nonconsumable electrode melting shall be vacuum or shall be inert gas at a pressure not higher than 1000 mm of mercury.

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

3.2.2 Sheet and strip produced to AMS4902 is acceptable to satisfy the melting and composition requirements provided that the composition meets Table 1, except that hydrogen shall meet the requirements of 3.1 when sampled in accordance with 4.3.1.

3.3 Condition

3.3.1 Unless otherwise specified, tubing shall be furnished welded, cold drawn, annealed, and descaled.

3.3.2 When specified by purchase order (see 8.6), tubing may be furnished according to 3.3.3, 3.3.4, or 3.3.5.

3.3.3 As welded.

3.3.3.1 Welded tube shall be processed to either of the following conditions.

3.3.3.1.1 The weld reinforcements shall be planished or bead rolled to meet requirement of 3.7.2.2. Tube shall be chemically descaled to remove surface contamination.

3.3.3.1.2 Tubing may be welded from material with thickness greater than, and with the diameter larger than, the final required dimensions and then redrawn to achieve final diameter and wall thickness. Redrawn tubing shall meet the wall thickness requirements of AMS2242.

3.3.4 Welded, annealed, and descaled.

3.3.5 Welded, stress relieved, and descaled.

3.4 Welding process shall be gas-metal-arc welded (GMAW) or gas-tungsten-arc welded (GTAW) using automated equipment and with or without filler metal. Filler metal shall be in accordance with AMS4951 or ERTi-2 per AWS A5.16.

3.4.1 Welding shall be performed by a qualified operator using a written and qualified welding procedure per AWS D17.1.

3.5 Annealing

Shall be as follows:

3.5.1 Heat to a temperature within the range 1200 to 1500 °F (649 to 816 °C), hold at the selected temperature within ±25 °F (±14 °C) for 15 to 120 minutes, and cool as required. Annealing times for material processed in a continuous furnace may be shortened to 2 minutes minimum. Pyrometry shall be in accordance with AMS2750.

3.6 Stress Relieved Condition

When specified, the tubing shall be stress relieved in accordance with 3.6.1.1 and shall be chemically descaled to remove surface contamination.

3.6.1.1 Heat to 1100 °F ± 25 °F (593 °C ± 14 °C) and soak for 2 hours ± 30 minutes and air or furnace cool. Pyrometry shall be in accordance with AMS2750.

3.7 Properties

Tubing shall conform to the following requirements:

3.7.1 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 - Tensile properties

Property	Value
Tensile Strength, minimum	50.0 ksi (345 MPa)
Yield Strength at 0.2% Offset	40.0 to 65.0 ksi (276 to 448 MPa)
Elongation in 2 inches (50.8 mm), minimum	20%

3.7.2 Flattening

3.7.2.1 Tubing with Nominal Wall Thickness Less than or Equal to 10% of Nominal Outside Diameter

A sample per 4.3.1.2 shall be flattened between platens under a gradually applied load until the distance between platens is equal to five times the nominal wall thickness of the tubing. The weld during flattening test shall be oriented at 90 degrees ± 5 degrees to the application of flattening loads. The specimen shall flatten without cracking. Tubing failing to meet flattening requirement shall alternatively meet bending requirement of 3.7.3.

3.7.2.2 Tubing with Nominal Wall Thickness Greater than 10% of Nominal Outside Diameter

The tubing shall not require a flattening test. The tubing shall meet the bend test requirement as specified in 3.7.3.

3.7.3 Bending

3.7.3.1 Shall not develop cracks, tears, breaks, or other flaws when bent per 3.7.3.2.

3.7.3.2 A sample per 4.3.1.2 shall be bent 90 degrees at room temperature around a suitable bend die having a centerline radius equal to three times the nominal outside diameter of the tubing. A center rod or ball type retractable mandrel inserted to the tangent of the bend or appropriate tube filler shall be used to support the inside of the tube during the tube bending operation to restrict flattening of the tube. Ovality of the specimen in the bend area shall not exceed 7%.

3.7.4 Flarability

3.7.4.1 Shall not develop cracks or other visible defects when flared per 3.7.4.2.

3.7.4.2 A sample per 4.3.2.1 shall be flared at room temperature by forcing it axially with a steady pressure over a hardened and polished tapered steel pin. The pin shall have a 74-degree included angle, to produce a flare having a permanent expanded outside diameter not less than 1.30 times the original nominal outside diameter.

3.7.5 Pressure Testing

Tubing shall show no bulges, leaks, pin holes, cracks, or other defects when subjected to an internal hydrostatic pressure per 3.7.5.1.

3.7.5.1 A sample per 4.3.1.2 shall be tested with hydrostatic pressure (P) sufficient to cause a tensile stress (S) of 40.0 ksi (275 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 from 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 = 40.0 ksi (275 MPa) tensile stress

D = nominal OD (nominal OD plus tolerance)

d = nominal ID (nominal OD minus twice the minimum wall thickness)

3.7.6 Surface Contamination

The surfaces of the tube shall be free of any oxygen-rich layer, such as alpha case (see 8.2), or other surface contamination when tested per 3.7.6.1.

3.7.6.1 A sample per 4.3.1.2 shall be metallographically examined to determine surface contamination, if any. The examination shall be of a metallographic cross section at 400X minimum magnification or by other method agreed upon by the purchaser.

3.7.7 Weld Quality

3.7.7.1 Welds on each tube following conditioning per 3.3 shall be tested per 3.7.7.2 and meet the acceptance criteria for Class A per AWS D17.1.

3.7.7.2 Weld on each tube in a lot shall be inspected visually, as well as, with a nondestructive inspection procedure established by the tubing manufacturer meeting any current industry specification (ultrasonic, radiographic, and/or eddy current). The procedure shall be demonstrated to be capable of detecting flaws larger than those specified for Class A per AWS D17.1.

3.8 General Quality

Tubing, as received by the 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, 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.

3.9 Tolerances

Each tube in the lot shall meet requirements specified here in.

3.9.1 Unless otherwise specified herein, tolerances shall conform to all applicable requirements of AMS2244; standard tolerances for diameter shall apply.

3.9.2 Wall Thickness

3.9.2.1 Thickness of the tubing in the area away from weld.

Except as noted in 3.3.1 and 3.3.3.1.2 for drawn tubing, the wall thickness of the tubing shall be as that of the sheet material thickness used in the fabrication of the tubing. The thickness tolerance shall be in accordance with AMS2242.

3.9.2.2 Thickness of the tubing in the weld area.

The face and root surface of the weld after planishing operation shall not be above the adjacent surface by more than 0.0025 inch. Neither face nor root surface shall be below the adjacent surface. Undercut at the weld toe of the face and root sides shall not be acceptable. The measurement shall be performed on both ends of the specimens sectioned for the flattening, flaring, and pressure tests.

3.9.3 Ovality

3.9.3.1 Ovality shall not exceed 2% in any section of the tubing for tubing with diameter to thickness ratios less than or equal to 100.

3.9.3.2 Ovality shall not exceed 4% in any section of the tubing for tubing with diameter to thickness ratios greater than 100.

3.10 Exceptions

Any exceptions shall be authorized by the purchaser and reported as in 4.4.2.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for Inspection

The producer of tubing shall supply all samples for the producer's tests and shall be responsible for the performance of all required tests. The 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

Composition (see 3.1), tensile properties (see 3.7.1), flattening (see 3.7.2) and/or bending (see 3.7.3), pressure test (see 3.7.5), surface contamination (see 3.7.6), weld quality (see 3.7.7), general quality (see 3.8), and tolerances (see 3.9) are acceptance tests and shall be performed on each heat or lot as applicable.