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400 Commonwealth Drive, Warrendale, PA 15096-0001

# AEROSPACE MATERIAL SPECIFICATION

SAE AMS 4945B

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Superseding AMS 4945A

## Titanium Alloy Tubing, Seamless, Hydraulic 3Al - 2.5V, Controlled Contractile Strain Ratio Cold Worked, Stress Relieved

(Composition similar to UNS R56320)



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 high fatigue 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 canceled and no superseding document has been specified, the last published issue of that document shall apply.

2.1 SAE Publications:

Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

| | |
|---|---|
| AMS 2244 | Tolerances, Titanium and Titanium Alloy Tubing |
| MAM 2244 | Tolerances, Metric, Titanium and Titanium Alloy Tubing |
| AMS 2249 | Chemical Check Analysis Limits, Titanium and Titanium Alloy |
| AMS 2634 | Ultrasonic Inspection, Thin Wall Metal Tubing |
| AMS 2809 | Identification, Titanium and Titanium Alloy Wrought Products |
| AS4076 | Contractile Strain Ratio Testing of Titanium Hydraulic Tubing |



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**TO PLACE A DOCUMENT ORDER:** (724) 776-4970 FAX: (724) 776-0790
**SAE WEB ADDRESS:** http://www.sae.org

2.2 ASTM Publications:

Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

| | |
|---|---|
| ASTM E 8 | Tension Testing of Metallic Materials |
| ASTM E 8M | Tension Testing of Metallic Materials (Metric) |
| ASTM E 120 | Chemical Analysis of Titanium and Titanium Alloys |
| ASTM E 1409 | Determination of Oxygen 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 Method |

2.3 U.S. Government Publications:

Available from DODSSP, Subscription Services Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

MS33611 Tube Bend Radii

2.4 ANSI Publications:

Available from ANSI, 11 West 42nd Street, New York, NY 10036-8002.

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

3. TECHNICAL REQUIREMENTS:

3.1 Composition:

Shall conform to the percentages by weight shown in Table 1, determined by wet chemical methods in accordance with ASTM E 120, by spectrochemical methods, or by other analytical methods acceptable to 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 (3.1.2) | -- | 0.015 (150 ppm) |
| Yttrium (3.1.1) | -- | 0.005 ( 50 ppm) |
| Residual Elements, each (3.1.1) | -- | 0.10 |
| Residual Elements, total (3.1.1) | -- | 0.40 |
| Titanium | remainder | |

3.1.1 Determination not required for routine acceptance.

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

3.1.3 Check Analysis: Composition variations shall meet the requirements of AMS 2249.

3.2 Melting Practice:

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, or plasma arc melting practice. The subsequent melt or melts shall be made using consumable electrode practice with no alloy additions permitted in the last consumable electrode melt.

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.

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 or ASTM E 8M 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 (2.5 mm) per minute above the yield strength.



TABLE 2 - Minimum Tensile Properties

| Property | Value |
|---|---|
| Tensile Strength | 125 ksi (862 MPa) |
| Yield Strength at 0.2% Offset | 105 ksi (724 MPa) |
| Elongation in 2 Inches (50.8 mm) | |
| Nominal Wall Thickness | |
| Up to 0.016 inch (0.41 mm), incl | 8% |
| Over 0.016 inch (0.41 mm) | 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/inch (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 = 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 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 MS33611.

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. Examination of tube surfaces shall be at 5 to 10X magnification.

TABLE 3 - Flattening Test

| 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, with some areas of partially transformed beta structure permissible. Standards shall be acceptable to purchaser. 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 agreed upon by purchaser and vendor.

3.4.7 Contractile Strain Ratio: The contractile strain ratio (CSR), when tested in accordance with AS4076, shall be not less than 1.3 for tubing sizes with wall thicknesses up to and including those indicated in Table 4. The CSR for tubing sizes up to and including those indicated in Table 5, shall be not less than 1.5.

TABLE 4 - Tubing Sizes for 1.3 Minimum Contractile Strain Ratio

| Nominal OD Inch | Nominal OD Millimeters | Maximum Wall Thickness Inch | Maximum Wall Thickness Millimeters |
|---|---|---|---|
| 3/16 | 4.8 | 0.020 | 0.51 |
| 1/4 | 6.4 | 0.022 | 0.56 |
| 3/8 | 9.5 | 0.032 | 0.81 |
| 1/2 | 12.7 | 0.043 | 1.09 |
| 5/8 | 15.9 | 0.054 | 1.37 |
| 3/4 | 19.0 | 0.065 | 1.65 |
| 7/8 | 22.2 | 0.077 | 1.96 |
| 1 | 25.4 | 0.088 | 2.24 |

TABLE 5 - Tubing Sizes for 1.5 Minimum Contractile Strain Ratio

| Nominal OD Inch | Nominal OD Millimeters | Maximum Wall Thickness Inch | Maximum Wall Thickness Millimeters |
|---|---|---|---|
| 1-1/4 | 31.8 | 0.087 | 2.21 |
| 1-1/2 | 38.1 | 0.090 | 2.29 |



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 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 AMS 2634, 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 ANSI/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 all applicable requirements of the following:

3.6.1 Outer Diameter: Shall be as specified in Table 6; tolerances shown include ovality.



TABLE 6A - Tolerances, Outer Diameter, Inch/Pound Units

| Nominal OD Inches | Tolerance Inch Plus | Tolerance Inch Minus |
|---|---|---|
| Over 0.093 to 0.187, incl | 0.002 | 0.000 |
| Over 0.187 to 0.499, incl | 0.003 | 0.000 |
| Over 0.499 to 0.749, incl | 0.004 | 0.000 |
| Over 0.749 to 0.999, incl | 0.004 | 0.001 |
| Over 0.999 to 1.499, incl | 0.004 | 0.002 |
| Over 1.499 to 1.999, incl | 0.005 | 0.002 |

TABLE 6B - Tolerances, Outer Diameter, SI Units

| Nominal OD Millimeters | Tolerance Millimeter Plus | Tolerance Millimeter Minus |
|---|---|---|
| Over 2.36 to 4.75, incl | 0.05 | 0.00 |
| Over 4.75 to 12.67, incl | 0.08 | 0.00 |
| Over 12.67 to 19.02, incl | 0.10 | 0.00 |
| Over 19.02 to 25.37, incl | 0.10 | 0.025 |
| Over 25.37 to 38.07, incl | 0.10 | 0.05 |
| Over 38.07 to 50.77, incl | 0.13 | 0.05 |

3.6.1.1 Diameter tolerances for tubing 0.093 inch (2.36 mm) and under or over 1.999 inches (50.77 mm) in nominal OD shall be as agreed upon by purchaser and vendor.

3.6.2 Inner Diameter: Shall be as specified in Table 7. The nominal inner diameter is defined as being equal to the nominal OD minus twice the nominal wall thickness.



TABLE 7A - Tolerances, Inner Diameter, Inch/Pound Units

| Nominal ID Inches | Tolerance Inch Plus | Tolerance Inch Minus |
|---|---|---|
| Up to 0.338, incl | 0.0015 | 0.0015 |
| Over 0.338 to 0.449, incl | 0.002 | 0.002 |
| Over 0.449 to 0.673, incl | 0.0025 | 0.0025 |
| Over 0.673 to 0.900, incl | 0.003 | 0.003 |
| Over 0.900 and above | 0.004 | 0.004 |

TABLE 7B - Tolerances, Inner Diameter, SI Units

| Nominal ID Millimeters | Tolerance Millimeter Plus | Tolerance Millimeter Minus |
|---|---|---|
| Up to 8.59, incl | 0.038 | 0.038 |
| Over 8.59 to 11.40, incl | 0.05 | 0.05 |

TABLE 7B - Tolerances, Inner Diameter, SI Units

| Nominal ID Millimeters | Tolerance Millimeter Plus | Tolerance Millimeter Minus |
|---|---|---|
| Over 11.40 to 17.09, incl | 0.064 | 0.064 |
| Over 17.09 to 22.86, incl | 0.08 | 0.08 |
| Over 22.86 and above | 0.10 | 0.10 |

3.6.3 Wall Thickness: All tubing 1.500 inches (38.10 mm) and under in nominal OD shall have a wall thickness not less than 95% of nominal.

3.6.4 Length and Straightness: Shall conform to AMS 2244 or MAM 2244.

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 the 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 ingot, 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 m) or three samples from each lot, whichever is greater.

4.3.3 Flarability: One sample per tube for lot sizes of four or less tubes and four samples for lot sizes of 5 to 39 tubes. For lot sizes of 40 or more tubes, one sample 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 specimen 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 parallel to the axis of the tube.

4.3.7 Microstructure: One sample from each lot.

4.3.8 Contractile Strain Ratio: Three per lot.

4.3.9 Ultrasonic Inspection and Tolerances: Each tube.

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

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 which will produce tubing meeting the technical requirements of this specification. 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.