AEROSPACE MATERIAL SPECIFICATION

AMS4946	REV. D

Issued 2002-10
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Superseding AMS4946C

Titanium Alloy Tubing, Seamless, Hydraulic 3Al - 2.5V, Texture Controlled Cold Worked, Stress Relieved

(Composition similar to UNS R56320)

RATIONALE

AMS4946D results from a Five Year Review and update of this specification and includes a reduction in hydrogen content (Table 1), changes in furnace class and instrumentation requirements (3.3.1), use of vacuum/inert gas furnaces (3.3.2), reduced flarability sampling (4.3.3), allows cracking on interior surfaces of flattening specimens at high strain areas, corrects errors in T flattening factors (Table 3) and revised reporting.

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.

1.3 Types

This specification covers the following types:

Type I - Tubing with 105 ksi (724 MPa) minimum yield strength

Type II - Tubing with 95 ksi (655 MPa) minimum yield strength

Type III - Tubing with 70 ksi (433 MPa) minimum yield strength

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.

TO PLACE A DOCUMENT ORDER: **Tel: 877-606-7323 (inside USA and Canada)**
Tel: +1 724-776-4970 (outside USA)
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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/AMS4946D

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 Alloy

AMS2634 Ultrasonic Inspection, Thin Wall Metal Tubing

AMS2750 Pyrometry

AMS2809 Identification, Titanium and Titanium Alloy Wrought Products

AS4076 Contractile Strain Ratio Testing of Titanium Hydraulic Tubing

AS33611 Tube Bend Radii

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 Direct Current Plasma and Inductively Coupled Atomic Emission 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	--	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 under vacuum 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 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 (371 °C) for not less than 2 hours after straightening. 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 All heat treatment operations shall be performed in 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 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 2 - TENSILE VALUES

Type	Property	Value
I	Tensile Strength	125 to 142 ksi (862 to 979 MPa)
	Yield Strength at 0.2% Offset	105 ksi (724 MPa) Minimum
	Elongation in 2 Inches (50.4 mm)	
	Nom. Dia. Up to 0.250 inch (6.35 mm), incl	10% Minimum
	Nom. Dia. Over 0.250 inch (6.35 mm)	14% Minimum
II	Tensile Strength	100 to 133 ksi (690 to 917 MPa)
	Yield Strength at 0.2% Offset	95 ksi (655 MPa) Minimum
	Elongation in 1 inch (6.35 mm)	13% Minimum
III	Tensile Strength	85 to 102 ksi (586 to 703 MPa)
	Yield Strength at 0.2% Offset	70 ksi (483 MPa) Minimum
	Elongation in 2 inches (50.8 mm)	15% Minimum

3.4.2 Flarability

Specimens as in 4.3.3 shall withstand flaring at room temperature, without formation of cracks or other visible defects when examined at 10X magnification, by being forced axially, with a 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 for Types I and II, and not less than 1.30 times the original nominal OD for Type III.

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 equivalent to the minimum rated yield strength 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:

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

where:

P = Test pressure in ksi (MPa)

S = Minimum Yield Strength in ksi (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 rotary 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. Flatness 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 (minimum 2 inches (51 mm) long) 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 the flattening factors 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. Additional standards may be agreed upon by purchaser and vendor for any tube sizes not listed in Table 3.

When low D to t ratio tubular products are tested, because the strain imposed due to geometry in unusually high on the inside surface at the 6 and 12 o'clock locations, cracks at these locations shall not be cause for rejection if the D to t ratio is less than twelve (12).

TABLE 3 - FLATTENING TEST

Nominal Tube Outer Diameter Inch	Nominal Tube Outer Diameter mm	Nominal Tube Wall Thickness Inch	Nominal Tube Wall Thickness mm	Material Type	Distance Between Plates Where t = Actual Wall Thickness
0.250	6.35	0.016	0.41	Type I	12t
0.250	6.35	0.016	0.41	Type II	9t
0.250	6.35	0.018	0.46	Type I	10t
0.250	6.35	0.020	0.51	Type I	10t
0.250	6.35	0.022	0.56	Type II	8t
0.250	6.35	0.022	0.56	Type I	10t
0.250	6.35	0.028	0.71	Type I	8t
0.250	6.35	0.028	0.71	Type III	6t
0.313	7.95	0.020	0.51	Type I	12t
0.375	9.53	0.019	0.48	Type I	11t
0.375	9.53	0.020	0.51	Type I	13t
0.375	9.53	0.022	0.56	Type I	13t
0.375	9.53	0.028	0.71	Type I	10t
0.375	9.53	0.032	0.81	Type I	9t
0.375	9.53	0.038	0.97	Type I	9t
0.375	9.53	0.042	1.07	Type I	8t
0.500	12.70	0.020	0.51	Type I	14t
0.500	12.70	0.022	0.56	Type I	14t
0.500	12.70	0.026	0.66	Type I	13t
0.500	12.70	0.035	0.89	Type I	10t
0.500	12.70	0.042	1.07	Type I	9t
0.500	12.70	0.043	1.09	Type I	9t
0.500	12.70	0.051	1.27	Type I	8t
0.500	12.70	0.056	1.42	Type I	8t
0.625	15.88	0.020	0.51	Type I	16t
0.625	15.88	0.023	0.58	Type I	15t
0.625	15.88	0.027	0.68	Type I	14t
0.625	15.88	0.032	0.81	Type I	13t
0.625	15.88	0.035	0.89	Type I	12t
0.625	15.88	0.044	1.12	Type I	10t
0.625	15.88	0.052	1.30	Type I	9t
0.625	15.88	0.054	1.37	Type I	9t
0.625	15.88	0.071	1.80	Type I	8t

TABLE 3 - FLATTENING TEST (CONTINUED)

Nominal Tube Outer Diameter Inch	Nominal Tube Outer Diameter mm	Nominal Tube Wall Thickness Inch	Nominal Tube Wall Thickness mm	Material Type	Distance Between Plates Where t = Actual Wall Thickness
0.750	19.05	0.020	0.51	Type I	17t
0.750	19.05	0.027	0.69	Type I	15t
0.750	19.05	0.039	0.99	Type I	12t
0.750	19.05	0.049	1.24	Type I	10t
0.750	19.05	0.052	1.32	Type I	10t
0.750	19.05	0.063	1.60	Type I	9t
0.750	19.05	0.065	1.65	Type I	9t
0.875	22.23	0.020	0.51	Type I	19t
0.875	22.23	0.032	0.81	Type I	14t
0.875	22.23	0.045	1.14	Type I	12t
0.875	22.23	0.050	1.27	Type I	11t
0.875	22.23	0.061	1.55	Type I	10t
1.000	25.40	0.020	0.51	Type I	20t
1.000	25.40	0.021	0.53	Type I	19t
1.000	25.40	0.028	0.97	Type I	17t
1.000	25.40	0.030	0.76	Type I	16t
1.000	25.40	0.035	0.89	Type I	15t
1.000	25.40	0.036	0.91	Type I	14t
1.000	25.40	0.051	1.30	Type I	12t
1.000	25.40	0.070	1.78	Type I	10t
1.000	25.40	0.088	2.24	Type I	9t
1.000	25.40	0.140	3.56	Type I	7t
1.250	31.75	0.026	0.66	Type I	19t
1.250	31.75	0.028	0.71	Type I	18t
1.250	31.75	0.045	1.14	Type I	14t
1.250	31.75	0.046	1.17	Type I	14t
1.250	31.75	0.065	1.65	Type I	12t
1.250	31.75	0.070	1.78	Type I	12t
1.250	31.75	0.087	2.21	Type I	11t
1.500	38.10	0.032	0.81	Type I	18t
1.500	38.10	0.049	1.24	Type I	15t
1.500	38.10	0.054	1.37	Type I	14t

3.4.6 Microstructure

Type I and Type II shall be predominantly an elongated wrought structure but some areas of partially transformed beta structure are acceptable. Type III shall be equiaxed wrought structure but some areas of partially transformed beta are acceptable. Standards shall be acceptable to purchaser unless standards for acceptance are specified by 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) for Types I and II tubing, when tested in accordance with AS4076, shall be between 1.3 and 3.5 for the tubing sizes with wall thicknesses indicated in Table 4. The CSR for tubing sizes indicated in Table 5, shall be between 1.5 and 3.5. Additional standards for acceptance may be agreed upon by purchaser and vendor for any tube sizes not listed.

TABLE 4 - TUBING SIZES FOR 1.3 - 3.5 CONTRACTILE STRAIN RATIO

Nominal OD Inches	Nominal OD Millimeters	Wall Thickness Inch	Wall Thickness Millimeters
3/16	4.8	0.020 max	0.51 max
1/4	6.4	0.022 max	0.56 max
3/8	9.5	0.032 max	0.81 max
1/2	12.7	0.043 max	1.09 max
5/8	15.9	0.054 max	1.37 max
3/4	19.0	0.065 max	1.65 max
7/8	22.2	0.077 max	1.96 max
1	25.4	0.088 max	2.24 max
1-1/4	31.8	0.071 and larger	1.80 and larger
1-1/2	38.1	0.066 and larger	1.68 and larger

TABLE 5 - TUBING SIZES FOR 1.5 - 3.5 CONTRACTILE STRAIN RATIO

Nominal OD Inches	Nominal OD Millimeters	Wall Thickness Inch	Wall Thickness Millimeters
1-1/4	31.8	0.070	1.78
1-1/2	38.1	0.065	1.65

3.5 Quality

Tubing, as received by purchaser, shall be uniform in appearance, quality, and condition, for all lengths of tubing within that lot, 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 AMS2634, Class AA, for ID, OD, and subsurface imperfections of all types and orientations (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 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 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 Inches Plus	Tolerance Inches Minus
	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 ID Millimeters					Tolerance Millimeter Plus	Tolerance Millimeter Minus
	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
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 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

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. Tensile testing shall include a minimum of one specimen obtained from the middle and each end of the furnace used to stress relieve the tube lot.