



AEROSPACE MATERIAL SPECIFICATION

AMS4946™**REV. G**Issued 2002-10
Revised 2025-03

Superseding AMS4946F

Titanium Alloy Tubing, Seamless, Hydraulic,
3Al - 2.5V, Texture Controlled,
Cold Worked, Stress Relieved
(Composition similar to UNS R56320)

RATIONALE

AMS4946G results from a Five-Year Review and update of this specification with changes to relocate Definitions (see 2.4), apply standard wording for reporting properties for product outside the size range in Table 6 (see 3.6.1.1), and update Applicable Documents (see Section 2), Microstructure (see 3.4.6), and Ordering Information (see 8.7).

1. SCOPE

1.1 Form

This specification covers a titanium alloy in the form of seamless tubing (see 8.7).

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 Type and Class

1.3.1 Tubing covered by this specification is classified by minimum yield strength as follows:

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 (483 MPa) minimum yield strength

1.3.2 Tubing covered by this specification is classified by surface finish treatment as follows:

Class 1 - Conventional acid-pickling surface finish treatment

Class 2 - Alternate surface finish treatment (requires qualification to AS5620) (see 8.8)

1.3.2.1 If no class is specified, Class 1 shall be supplied.

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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
AMS2634	Ultrasonic Inspection, Thin Wall Metal Tubing
AMS2750	Pyrometry
AMS2809	Identification, Titanium and Titanium Alloy Wrought Products
AS1814	Terminology for Titanium Microstructures
AS4076	Contractile Strain Ratio Testing of Titanium Hydraulic Tubing
AS5620	Titanium Hydraulic Tubing, Ti-3Al-2.5V Cold Worked and Stress Relieved, Up to 35000 kPa (5080 psi), Requirements for Qualification Testing and Control
AS7766	Terms Used in Aerospace Metals Specifications
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 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 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 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 (Roughness, Waviness, and Lay)

2.4 Definitions

Terms used in AMS are defined in AS7766.

2.4.1 Terminology relating to titanium microstructures is presented in AS1814.

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 (see 3.1.1)	--	0.005 (50 ppm)
Other Elements, each (see 3.1.1)	--	0.10
Other Elements, total (see 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 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 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 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 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 (50.8 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 (25.4 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 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, pinholes, 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 in/in (0.002 mm/mm) of diameter is acceptable. The hydrostatic pressure (P) shall be determined from Equation 1:

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

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 shall be agreed upon by the purchaser and producer for any tube sizes not listed in Table 3 (see 8.7).

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

Table 3 - Flattening test

Nominal Tube Outer Diameter Inches	Nominal Tube Outer Diameter Millimeters	Nominal Tube Wall Thickness Inches	Nominal Tube Wall Thickness Millimeters	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 Inches	Nominal Tube Outer Diameter Millimeters	Nominal Tube Wall Thickness Inches	Nominal Tube Wall Thickness Millimeters	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

Types I and II shall be predominantly an elongated wrought alpha 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 the purchaser unless standards for acceptance are specified by the 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 the purchaser and producer (see 8.7).

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 (see 8.3). 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 the purchaser and producer for any tube sizes not listed (see 8.7).

Table 4 - Tubing sizes for 1.3 to 3.5 contractile strain ratio

Nominal OD Inches	Nominal OD Millimeters	Wall Thickness Inches	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 to 3.5 contractile strain ratio

Nominal OD Inches	Nominal OD Millimeters	Wall Thickness Inches	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 the 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

3.5.2.1.1 Class 1 tubing 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.

3.5.2.1.2 Class 2 tubing shall be an OD surface treatment that differs from Class 1 criteria and meets the performance criteria defined in AS5620 (see 8.8).

3.5.2.2 ID Surface

3.5.2.2.1 Class 1 tubing shall show a uniform matte finish, produced by abrasive blasting with grit not larger than 100 mesh (150 μ m) followed by forced-flow acid pickling to remove not less than 0.0005 inch (0.013 mm) from the wall thickness.

3.5.2.2.2 Class 2 tubing shall be an ID surface treatment that differs from Class 1 criteria and meets the performance criteria defined in AS5620 (see 8.8).

3.5.2.3 Surface Texture

Shall be not greater than 63 microinches (1.6 μm) Ra on the ID and 32 microinches (0.8 μm) Ra 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 Inch Plus	Tolerance Inch 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 the purchaser and producer and reported per 4.5.2 (see 8.7).

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.

3.7 Exceptions

Any exceptions shall be authorized by the 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 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

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

4.2.2 Periodic Tests

Pressure testing (see 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 the 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 a 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.

4.3.3 Flarability

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

4.3.3.1 Samples for the flarability (see 3.4.2) test shall be full tubes or sections cut from a tube. The end of each 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

Specimen length shall be 9 inches (229 mm) minimum. Test with a pressure as determined in 3.4.3 for a minimum of 2 minutes.

4.3.5 Bending

Two samples from each lot.

4.3.6 Flattening

Three samples minimum and 10 samples maximum. One sample is required for each 135 feet (41 m) of tubing. Specimens of the full section of the tube not less than 2 inches in length shall be cut from separate tubes.

4.3.7 Microstructure

One sample from each lot.

4.3.8 Contractile Strain Ratio (CSR)

Three samples per lot.

4.3.9 Ultrasonic Inspection

Each tube.