SAE Aerospace
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AEROSPACE MATERIAL SPECIFICATION

SAE AMS 4946

Issued OCT 2002

Titanium Alloy Tubing, Seamless, Hydraulic 3Al - 2.5V, Texture Controlled 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 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:

1.3.1 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 canceled 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: 724-776-4970 (outside USA)
Fax: 724-776-0790
Email: custsvc@sae.org
SAE WEB ADDRESS: http://www.sae.org

2.1 SAE Publications:

Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001 or www.sae.org.

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 2750	Pyrometry
AMS 2809	Identification, Titanium and Titanium Alloy Wrought Products
AS4076	Contractile Strain Ratio Testing of Titanium Hydraulic Tubing
AS33611	Tube Bend Radii
AMS-H-81200	Heat Treatment of Titanium and Titanium Alloys

2.2 ASTM Publications:

Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959 or www.astm.org.

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

2.3 ASME Publications:

Available from ASME, 3 Park Avenue, New York, NY 10016.

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	--	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 Check Analysis: Composition variations shall meet the applicable 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. Tubing which is rotary straightened after final reduction shall be stress relieved at a minimum temperature of 700 °F for not less than two hours after straightening.

3.3.1 Heat treating equipment shall conform to the requirements of AMS-H-81200. Furnaces shall meet the requirements of AMS 2750 for Type A furnaces. Uniformity shall be between ±25 °F (±14 °C) with a readability requirement of ±2° (±1°).

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 - 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", incl	10% Minimum
	Nom. Dia. Over 0.250"	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	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	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, 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:

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

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.

TABLE 3 - Flattening Test-Inch/Pound Units

Nominal Tube Outer Diameter	Nominal Tube Wall Thickness	Material Type	Distance Between Plates Where t = Actual Wall Thickness
0.250	0.016	Type I	12t
0.250	0.016	Type II	9t
0.250	0.018	Type I	10t
0.250	0.020	Type I	10t
0.250	0.022	Type II	8t
0.250	0.022	Type I	10t
0.250	0.028	Type I	9t
0.250	0.028	Type III	6t
0.313	0.020	Type I	12t
0.375	0.019	Type I	11t
0.375	0.020	Type I	13t
0.375	0.022	Type I	13t
0.375	0.028	Type I	10t
0.375	0.032	Type I	9t
0.375	0.038	Type I	9t
0.375	0.042	Type I	8t
0.500	0.020	Type I	14t
0.500	0.022	Type I	14t
0.500	0.026	Type I	13t
0.500	0.035	Type I	10t
0.500	0.042	Type I	9t
0.500	0.043	Type I	9t
0.500	0.051	Type I	8t

TABLE 3 - Flattening Test-Inch/Pound Units (Continued)

Nominal Tube Outer Diameter	Nominal Tube Wall Thickness	Material Type	Distance Between Plates Where t = Actual Wall Thickness
0.500	0.056	Type I	8t
0.625	0.020	Type I	16t
0.625	0.023	Type I	15t
0.625	0.027	Type I	14t
0.625	0.032	Type I	13t
0.625	0.035	Type I	12t
0.625	0.044	Type I	10t
0.625	0.052	Type I	9t
0.625	0.054	Type I	9t
0.625	0.071	Type I	8t
0.750	0.020	Type I	17t
0.750	0.027	Type I	15t
0.750	0.039	Type I	12t
0.750	0.049	Type I	10t
0.750	0.052	Type I	10t
0.750	0.063	Type I	9t
0.750	0.065	Type I	9t
0.875	0.020	Type I	19t
0.875	0.032	Type I	14t
0.875	0.045	Type I	12t
0.875	0.050	Type I	11t
0.875	0.061	Type I	10t
1.000	0.020	Type I	20t
1.000	0.021	Type I	19t
1.000	0.028	Type I	17t
1.000	0.030	Type I	16t
1.000	0.035	Type I	15t
1.000	0.036	Type I	14t
1.000	0.051	Type I	12t
1.000	0.070	Type I	10t
1.000	0.088	Type I	9t
1.000	0.140	Type I	8t
1.250	0.026	Type I	19t
1.250	0.028	Type I	18t
1.250	0.045	Type I	14t
1.250	0.046	Type I	14t

TABLE 3 - Flattening Test-Inch/Pound Units (Continued)

Nominal Tube Outer Diameter	Nominal Tube Wall Thickness	Material Type	Distance Between Plates Where t = Actual Wall Thickness
1.250	0.065	Type I	12t
1.250	0.070	Type I	12t
1.250	0.087	Type I	11t
1.500	0.032	Type I	18t
1.500	0.049	Type I	15t
1.500	0.054	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 shall be acceptable. Type III shall be equiaxed wrought structure but some areas of partially transformed beta will be 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 2.5 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 - 2.5 Contractile Strain Ratio

Nominal OD Inch	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	1.81 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 Inch	Nominal OD Millimeters	Maximum Wall Thickness Inch	Maximum 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 AMS 2634, 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 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

3.6.2 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 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:

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 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 shall be tested.

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: Specimen length 9 inches (229 mm) minimum. Test with a pressure as determined in paragraph 3.4.3 for a minimum of two minutes.

4.3.5 Bending: Two specimens from each lot.

4.3.6 Flattening: Three samples minimum and ten 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 two 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 specimens per lot.

4.3.9 Ultrasonic Inspection: 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.

4.3.11 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 is waived by purchaser.