AEROSPACE MATERIAL SPECIFICATION

AMS4945™	REV. H

Issued 1989-01
Revised 2020-02

Superseding AMS4945G

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

(Composition similar to UNS R56320)

RATIONALE

AMS4945H results from a Five-Year Review and update of this specification that adds additional controls on produced material (8.6).

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 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

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AMS2809 Identification, Titanium and Titanium Alloy Wrought Products

ARP1917 Clarification of Terms Used in Aerospace Metals Specifications

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 E8/E8M Tension Testing of Metallic Materials

ASTM E539 Analysis of Titanium Alloys by 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 Titanium and Titanium Alloys by the Inert Gas Fusion Thermal Conductivity/Infrared Detection Method

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

ASTM E2994 Analysis of Titanium and Titanium Alloys by Spark Atomic Emission Spectrometry and Glow Discharge Atomic Emission Spectrometry

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)

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 (3.1.1)	--	0.005 (50 ppm)
Other Elements, each (3.1.1)	--	0.10
Other Elements, total (3.1.1)	--	0.40

3.1.1 Determination not required for routine acceptance.

3.2 Check Analysis

Composition variations shall meet the applicable requirements of AMS2249.

3.3 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.

3.3.1 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.

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

3.4 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.

3.4.1 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.

3.4.2 Heat treatment operations shall be performed under vacuum or inert gas.

3.5 Properties

Tubing shall conform to the following requirements:

3.5.1 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 - 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%

3.5.2 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 74 degree included angle to produce a flare having a permanent expanded OD not less than 1.20 times the original nominal OD.

3.5.3 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 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 = 105 ksi (724 MPa)

D = nominal OD

d = nominal ID

3.5.4 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

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 AS33611.

3.5.5 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

3.5.5.1 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.

3.5.6 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 producer.

3.5.7 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

3.6 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.

3.6.1 Each tube shall be ultrasonically inspected in accordance with AMS2634, Class AA, for ID, OD, and subsurface imperfections of all types and orientation (longitudinal and transverse).

3.6.2 Surface Condition

3.6.2.1 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.

3.6.2.2 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.

3.6.2.3 Surface Roughness

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.

3.6.2.4 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.

3.7 Tolerances

Shall conform to all applicable requirements of the following:

3.7.1 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

3.7.1.1 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 producer.

3.7.2 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

3.7.3 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.

3.7.4 Length and Straightness

Shall conform to AMS2244.

3.8 Any exceptions shall be authorized by 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 producer'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 producer 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 for each 1000 feet (305 m) or three samples from each lot, whichever is greater.

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 producer.

4.3.5 Bending

Two samples from each lot.

4.3.6 Flattening

One sample for each 135 feet (41 m) of tubing or ten 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 is waived by purchaser.

4.4.2 Producer shall establish parameters for the process control factors that will produce tubing meeting the technical requirements of this specification. If necessary to make any change in parameters for the process control factors, producer 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

4.4.2.1.1 Any of the above process control factors for which parameters are considered proprietary by the producer may be assigned a code designation. Each variation in such parameters shall be assigned a modified code designation.

4.5 Reports

4.5.1 The producer shall furnish with each shipment a report showing the producer identity, country where the metal was melted (e.g., final melt in the case of metal processed by multiple melting operations), the results of tests for composition of each heat and for the hydrogen content, tensile properties, flarability, bending, flattening,

microstructure, and contractile strain ratio of each lot, and state that the tubing conforms to the other technical requirements. This report shall include the purchase order number, lot number, AMS4945H, product form, size, and quantity.

4.5.2 When material produced to this specification is beyond the sizes allowed in the scope or tables, or other exceptions authorized by purchaser are taken to the technical requirements listed in Section 3, the report shall contain a statement "This material is certified as AMS4945H(EXC) because of the following exceptions:" and the specific exceptions shall be listed (also see 5.1).

4.6 Resampling and Retesting

If any specimen used in the above tests fails to meet the specified requirements, disposition of the tubing may be based on the results of testing three additional specimens, from tubes not tested in the original sampling, for each original nonconforming specimen. Except as in 4.6.1, failure of any retest specimen to meet the specified requirements shall be cause for rejection of the tubing represented. Results of all tests shall be reported.

4.6.1 The resampling for contractile strain ratio (CSR) test failures shall be done using three samples from the same tube. The average of the three retest results and the initial result shall meet the CSR requirement.

5. PREPARATION FOR DELIVERY

5.1 Identification

In accordance with AMS2809. When technical exceptions are taken (see 4.5.2), the material shall be marked with AMS4945H(EXC).

5.2 Packaging

5.2.1 A lot of tubing may be packaged in small quantities and delivered under the basic lot approval provided lot identification is maintained.

5.2.2 Tubing shall be prepared for shipment in accordance with commercial practice and in compliance with applicable rules and regulations pertaining to the handling, packaging, and transportation of the tubing to ensure carrier acceptance and safe delivery.

6. ACKNOWLEDGMENT

A producer shall include this specification number and its revision letter in all quotations and when acknowledging purchase orders.

7. REJECTIONS

Tubing not conforming to this specification, or to modifications authorized by purchaser, will be subject to rejection.

8. NOTES

8.1 Revision Indicator

A change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

8.2 An oxygen-rich layer, such as alpha case, is hard and brittle and results in marked lowering of fatigue properties.

8.3 Terms used in AMS are clarified in ARP1917.

8.4 Dimensions and properties in inch/pound units and the Fahrenheit temperatures are primary; dimensions and properties in SI units and the Celsius temperatures are shown as the approximate equivalents of the primary units and are presented only for information.

8.5 Conformance to contractile strain ratio test requirements requires control of processing effects on crystallographic texture. This control is necessary for optimum fatigue strength and for consistency in production bending.

8.6 It is the Purchaser's obligation to ensure that product they procure or resell as AMS4945H has any exceptions approved by their subsequent purchaser.

8.7 Purchase documents should specify not less than the following:

AMS4945H
Size of tubing desired
Quantity of tubing desired

8.8 Unless otherwise specified, the material producer shall work to the revision of this specification (AMS4945) in effect on the date of order placement. Unless otherwise specified, material manufactured and certified to the immediately previous revision of this specification (AMS4945) may be procured and used until inventory is depleted.